Independent Engineering Assessment of the New Orleans Temporary Outflow Canal Pumps

Prepared by

PARSONS

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This report was prepared for the Department of Defense Inspector General by Parsons and is based on information provided by the United States Army Corps of Engineers (USACE), Moving Water Industries (MWI), and the Sewerage and Water Board of New Orleans (SWB). Parsons prepared this report based on information available in October 2008 and subsequent interviews. The information presented herein provides an independent engineering assessment of the adequacy of the pump testing of the pump systems provided by MWI and identification of potential vulnerabilities of the hydraulic pumping systems to failures for the 40 hydraulic pumping systems installed at 17th Street, London Avenue, and Orleans Avenue Canals.

TABLE OF CONTENTS

List of Tables

List of Figures

Abbreviations and Acronyms

ANSI	American National Standards Institute
API	American Petroleum Institute
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
CCTV	Closed circuit television
cfs	Cubic feet per second
DoDIG	Department of Defense Inspector General
ERDC	Engineer Research and Development Center
FEM	Facilities & Equipment Maintenance
GAO	United States Government Accountability Office
GHz	Gigahertz
gpm	Gallons per minute
HI	Hydraulic Institute
HPO	Hurricane Protection Office
HPU	Hydraulic Power Units
Hz	Hertz
ICS	Interim Closure Structure
IP	Internet protocol
kVA	kilovolt Ampere
mph	Miles per hour
MTBF	Mean time between failures
MWI	Moving Water Industries
NEC	National Electrical Code
NFPA	National Fluid Power Association
OIM	Operations Instruction Manual
OSC	Office of Special Counsel
psi	Pounds per square inch
psig	Pounds per square inch gauge
PTC	Performance Testing Code
QA	Quality Assurance
QAR	Quality Assurance Report
rpm	Revolutions per minute
SCADA	Supervisory Control and Data Acquisition
SWB	Sewerage and Water Board
U.S.	United States
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation

Executive Summary

After Hurricane Katrina struck New Orleans on August 29, 2005, the U.S. Army Corps of Engineers (USACE) immediately started rebuilding the canal walls along the three main drainage canals and implementing additional flood protection for the City of New Orleans. The mission was to complete these additional flood protection features by June 2006 in anticipation of the 2006 hurricane season. USACE installed three temporary pumping structures with floodgates at the outfall of the three main drainage canals to Lake Pontchartrain. The gates were designed to remain open under normal operating conditions and be closed during a storm event when storm surge from Lake Pontchartrain might exceed safe levels. With the gates shut, the storm surge from Lake Pontchartrain would be prevented from entering the drainage canals, though the pump systems would still allow for the discharge of stormwater being pumped by the New Orleans Sewerage and Water Board (SWB). A total of 40 large capacity hydraulic pumps were installed by USACE in 2006 to assist with the removal of stormwater from the three main drainage canals into the lake when the gates were closed. Additionally, 19 direct drive pumps were installed in 2007. This ensured the canal water elevations were kept at "safe" levels as established by USACE geotechnical engineers. Approximately 16,600 cubic feet per second (cfs) (7.5 million gallons per minute [gpm]) in pumping capacity was designed, procured, constructed, and tested in approximately 21 months.

Moving Water Industries (MWI) provided the major equipment for the hydraulic pumping systems. A USACE inspection team was dispatched to MWI to observe and record the equipment assembly and testing at the factory prior to shipment in order to facilitate the objectives within the timeframe allowed. During this period of observations, questions were raised by a whistleblower relative to observed results and testing protocol for some of the various startup and performance tests of the MWI hydraulic pumping unit. These questions led to formal investigations by USACE, the Department of Defense Inspector General's (DoDIG's) Office, and the U.S. Government Accounting Office (GAO), each of which issued reports on their findings. Subsequent to the release of those reports, questions continued to be raised by the Office of Special Counsel (OSC) regarding the adequacy of the pump equipment testing and vulnerability to failure in the event of a hurricane; therefore the OSC recommended that a thorough and impartial investigation be conducted by independent professional engineers.

In response to a request for engineering services by the DoDIG, Parsons assembled a team of professional engineers experienced in pump station design, operations, maintenance, and testing requirements This team's objective was to provide an independent engineering assessment of the pump testing adequacy and to identify potential vulnerabilities of the temporary hydraulic pumping systems at 17th Street Canal, London Avenue Canal, and Orleans Avenue Canal. In order to address these two aspects of the temporary pump stations' readiness, Parsons assembled two separate but collaborative teams. One team was assembled for the testing adequacy evaluation and the other team was assembled for the vulnerability analysis.

The testing adequacy analysis was conducted through a progression of intelligence gathering. This effort started with a review of existing test data and reports that had been developed to date. After reviewing the available data, the team conducted site visits at the New Orleans temporary pump stations at 17th Street Canal, London Avenue Canal, and Orleans Avenue Canal. During this site visit, interviews with USACE project officials and operations staff at the Hurricane Protection Office (HPO) and the New Orleans SWB Director were conducted. While in New Orleans, the team was presented with the testing methodology conducted by the USACE Engineer Research and Development Center (ERDC). Details of the assumptions and protocols employed by ERDC during the model testing were discussed comprehensively with ERDC. Following the site visit to New Orleans, the team conducted interviews with individuals from the pump manufacturer, MWI in Deerfield Beach, Florida. The Parsons team toured the facilities to observe the testing configurations and fabrication methods employed by MWI. Additional engineering data was gathered from MWI to facilitate assessment of the factory tests. Once the MWI factory visit was completed, the USACE Jacksonville District Quality Assurance (QA) team was interviewed to obtain their first hand observations during the hydraulic pump fabrication and testing. The QA team substantially confirmed the observations documented in the DoDIG and GAO reports. Finally, the Parsons team met with the whistleblower at the local USACE Palm Beach Gardens office to obtain first hand information on the testing of the pumps. The team was presented with a detailed account on the testing and observation procedures.

The vulnerability progression was similar to the testing adequacy approach including all of the site visits and interviews discussed above. In addition, this intelligence gathering effort included a supplemental trip to New Orleans to discuss the sequence of events associated with the acceptance testing and a more in-depth discussion regarding the maintenance program. The vulnerability analysis inherently involves the judgment of professional engineers using the data provided, supplemented by experience to render an opinion of system vulnerability. This effort is detailed in Section 3 of this report which describes the systematic process of identification and categorization of vulnerabilities. The areas studied were mechanical, electrical, structural, operational, and the maintenance program.

After the aforementioned data was analyzed and the conclusions documented the Parsons team reviewed performance data obtained during Hurricanes Gustav and Ike. This approach helped the team maintain maximum objectivity in analyzing pre-Gustav records.

The information reviewed in preparing this report included prior reports, data previously gathered by the DoDIG including documentation submitted by a whistleblower to the U.S. Office of Special Counsel, information Parsons requested during the course of the assessment, and interviews Parsons requested in their assessment plan.

The findings and conclusions of the Parsons team are as follows:

1. Based on the information provided and the interviews performed, the Parsons team found that there were issues with the factory testing and changes to testing procedures by USACE that took place during the testing process. Further investigations also show issues raised by the whistleblower have been rectified in the field and the pumps re-tested for full functionality. Therefore, it is the Parsons team’s opinion that the hydraulic pump systems have been adequately tested for their intended purpose. Contract administration and compliance issues were

addressed by others under previously issued reports and are not part of the scope for this effort.

2. The second part of the report deals with identifying potential vulnerabilities to failure of the 40 hydraulic pumping systems installed. It is the opinion of the Parsons team that given the project objectives, the selection of hydraulic pumping systems was appropriate. These systems are designed for use where rapid deployment is desired and the need to accommodate flexible site configurations is necessary. While hydraulic pumping systems inherently require more maintenance than other less flexible and longer lead time pumping systems, these hydraulic systems exhibit no higher level of vulnerability than other similarly installed systems with similar complexity, as long as the recommended inspection and maintenance activities occur. The temporary nature of this installation also affects the vulnerability analysis. For example, corrosion protection measures for a temporary facility are different than those for a permanent installation, since the design life of the temporary structure is much less. It is the opinion of the Parsons team that as long as the permanent facilities proceed according to schedule and a thorough inspection and maintenance program is followed for the temporary facilities, there are no immediate vulnerabilities to catastrophic failures with the hydraulic pumping systems or their supporting systems.

3. On August 31, 2008, Hurricane Gustav made land fall, with a hurricane force of a Category 2 storm, the Louisiana coast experienced torrential rain and high winds of approximately 100 miles per hour (mph), which generated a storm surge in Lake Pontchartrain of 4.8 feet. Records show that the USACE canal teams received orders to close the canal gates at the temporary outflow canal pump stations at the 17th Street and London Avenue canals, cutting off the canals outflow to Lake Pontchartrain in anticipation of the storm surge associated with the high winds. Pumps were put into service and the two canals were successfully kept at the safe water levels. The Orleans Avenue gates were not shut as the water levels were at a safe level.

   On the morning of September 12, 2008, Hurricane Ike made land fall as a Category 3 wind force generating a storm surge in Lake Pontchartrain of approximately 5.2 feet. The coast experienced rain and winds of around 25 mph and at the temporary pump stations, the USACE canal team received orders to close the canal gates cutting off the canals' outflow to Lake Pontchartrain. Again pumps were put into service and the two canals were successfully kept at the safe water levels. The Orleans Avenue gates were not shut as the water levels were below its designated safe level.

   It is the opinion of the Parsons team that the temporary hydraulic pumping systems performed successfully, keeping the water levels of the canals at the determined safe level for both hurricanes.

Section 1 – Introduction

1.1 Background

Rainwater and other sources of stormwater from the City of New Orleans are collected via a system of interior canals and pumped by the New Orleans SWB into three main drainage canals located at 17th Street, London Avenue, and Orleans Avenue. These three canals historically discharged water by gravity feed to Lake Pontchartrain as part of the local flood control system.

On August 29, 2005, Hurricane Katrina blew across the City of New Orleans with winds in the Category 3 range of 127 mph. Tidal surge caused Lake Pontchartrain to rise to a level that not only prevented gravity discharge but also caused the levee protection system along the outfall canals to fail resulting in the well documented catastrophic flooding of New Orleans in 2005. In an effort to mitigate future occurrences similar to that experienced in Katrina, USACE was authorized to design and construct a protection system along each of the three main drainage canals. The protection system includes reinforcement of the levees, construction of an operable gate structure (flood gates) to protect against storm surge and the installation of temporary pumping systems.

USACE procured and installed 40 large capacity hydraulic pumping systems to provide pumping capacity at the 17th Street Canal, London Avenue Canal, and Orleans Avenue Canal. Each hydraulic pumping system consists of the pumping unit, hydraulic oil supply and return lines, and water discharge piping. The 60-inch diameter water pump unit contains a Hydraulic Power Unit (HPU) with a diesel engine and hydraulic pump. The supporting systems include the structural support system, electronic data and communication system, the electrical support system, and the mechanical support system.

Permanent pump stations are scheduled to be constructed by 2013. When the newly constructed flood gates are closed, blocking the normally occurring gravity flow, the temporary pump systems pump the collected stormwater from the drainage canals to Lake Pontchartrain. Approximately 16,600 cubic feet per second (cfs) (7.5 million gpm) in pumping capacity was designed, procured, constructed, and tested in approximately 21 months. Table 1-1 below is a summary of the general configuration of the three temporary pump stations:

Table 1-1—Summary of the General Configuration of the Three Pump Stations

Pump Station	Hydraulic Pump	Direct Drive Pump	Portable Pump
17th Street Canal	18	11	20
London Ave. Canal	12	8	–
Orleans Ave. Canal	10	–	–

MWI was selected by USACE to provide the major equipment for the hydraulic pumping systems. In order to facilitate the objectives within the timeframe allowed, USACE decided to send an inspection team to MWI, to observe and record the equipment assembly and testing that occurred at the factory prior to shipment of the equipment to the sites in New Orleans. During this period of observations at the pump manufacturer, questions were raised relative to observed results and testing protocol for some of the various startup and performance tests of the hydraulic pumping systems provided by MWI. These questions, raised by a whistleblower, led to a formal investigation by USACE, the DoDIG's Office, and the GAO, each of which issued reports on their findings. Subsequent to the release of those reports, questions continued to be raised regarding the pumping equipment.

1.2 Scope

Parsons was retained in response to the questions raised subsequent to the aforementioned reports and the recommendation by the OSC that a thorough and impartial investigation be conducted by independent professional engineers. The main objective was to obtain an outside opinion from a professional engineering company to resolve lingering and additional questions regarding the capability of the pumping systems.

The overall objectives of the assessment are to review the adequacy of testing of the temporary pumping systems and to identify and assess vulnerabilities of the hydraulic pumping systems to failures in the event of a hurricane (specifically a 10-year, 24-hour rainfall event to which USACE designed the systems). This assessment does not include the direct-drive, diesel-driven pumping systems supplied by others, the portable pumps at 17th Street temporary pump station, or the floodwall and levee reinforcement protection.

1.3 Standards and References

Industry practice for the design and testing of large flood control pumps and pumping stations typically follows the Hydraulic Institute (HI) standards for various types of pumps. These standards are printed by the American National Standards Institute (ANSI) and are reviewed on a minimum 5-year cycle as required by changes in technology and updates, and by canvassing of engineers, equipment manufacturers, and end-users. The Pump Intake Design Standard (ANSI/HI 9.8, 1998) also addresses when the acceptance criteria for physically modeling the pump station sump and approach canal can be relaxed.

MWI staff advised the Parsons team that the codes and standards used by their company for the design, manufacture, and assembly of their pumping systems are the ANSI/HI standards for vertical pumps, the American Society of Mechanical Engineers (ASME) Performance Testing Code (PTC) 8.2, Centrifugal Pumps and the ASME B31 set of process piping standards.

The types of pumping systems used at the temporary pump stations are unique in the sense that there is not a specific HI standard, which covers this patented, hybrid submersible axial, and mixed-flow propeller pump configuration. The Parsons team concluded that the most applicable classification is the vertical pump classification as described by HI. Applicable ANSI/HI standards for the design and testing of the water pumps include, but are not limited to the following list of 2002 editions:

2.1 – 2.2	Vertical Pumps for Nomenclature and Definitions
2.3	Vertical Pumps for Design and Application
2.4	Vertical Pumps for Installation, Operation and Maintenance
2.6	Vertical Pump Tests
9.8	Centrifugal and Vertical Pump Intake Design

Other applicable standards used in this report are:

National Electric Code (NEC) – 2008 Edition
ASME Code B31 for Standard of Pressure Piping
ASME Code 31.3 for Standard for Process Piping
American Society of Civil Engineers (ASCE) 7-02 Minimum Design Loads for Building and Other Structures (Applicable at the time of design)

Section 2 – Testing Adequacy Analysis

2.1 Pump Unit Description

Each hydraulic pump unit consists of two main components. The first component is a drive unit that consists of a prime mover (a Caterpillar diesel engine), which drives a double vane hydraulic pump (made by Denison) rated for 3,200 pounds per square inch (psi) complete with an oil reservoir. This whole first component is labeled the HPU for the purposes of this report. (Refer to Figure 2-1.) The second component, the MWI water pump, consists of an encased impeller, which is driven by a Rineer hydraulic motor. This hydraulic motor, which is surrounded by the pumped water, turns a short vertical shaft connected to the stainless steel axial-flow impeller and is connected to the HPU by a twin set of hydraulic hoses and pipes.

The temporary pumping facilities at each canal are similar in configuration, varying in total capacity from 9200 cfs at 17th Street, 5200 cfs at London Avenue to 2200 cfs at Orleans Avenue. There are a total of 40 of the large hydraulic pump units distributed among the three temporary pumping facilities.

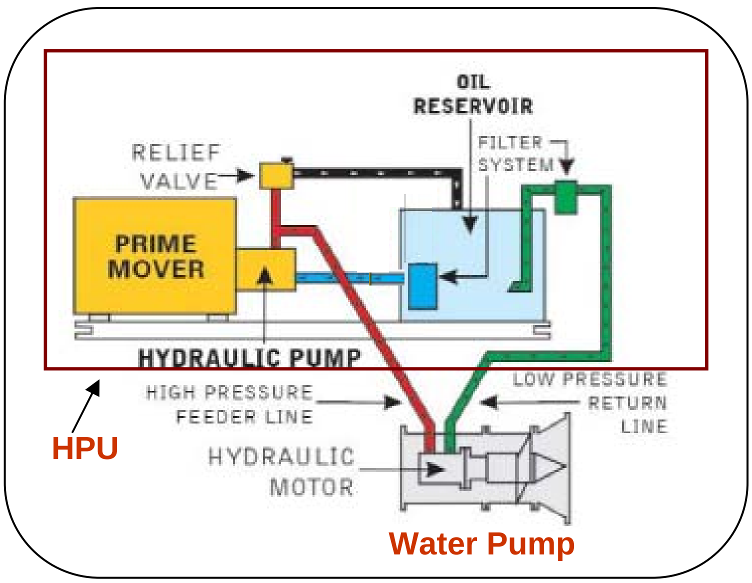

Figure 2-1—Pump Unit Diagram

2.2 Testing Summary

The tests performed by MWI, USACE, and ERDC on the HPU pump equipment can be divided into three different categories—factory, field, and laboratory. A time line of these activities is shown in Figure 2-2.

The factory testing included testing of each of the individual HPUs, performance testing of the water pumps using both a scaled model and full-sized prototype pump, and pressure testing of the full-sized prototype pumps.

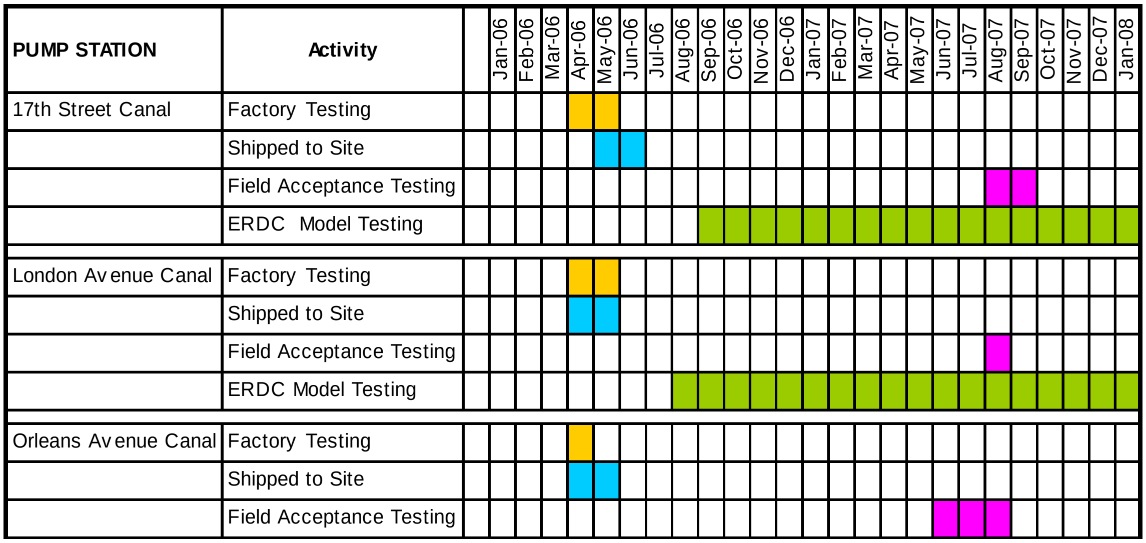

Figure 2-2—Testing Timeline

The factory testing took place at the manufacturer's facilities in Deerfield Beach, Florida and Sebastian, Florida. The field testing was performed as the pumps were installed at the three temporary pump stations in New Orleans and consisted of performance, acceptance, and endurance testing. The laboratory testing performed by ERDC involved scaled physical models of the approach channels and pump sump areas that were used to characterize the approach flow hydraulics and the hydraulics of the intakes to the pumps. This testing took place at the ERDC facilities in Vicksburg, Mississippi. It should be noted that the factory, field, and laboratory testing did not occur sequentially, but they were performed concurrently as the equipment was being manufactured and the stations were being designed and constructed.

The Parsons team reviewed the pump test reports provided and found the reports to be complete and detailed, containing comprehensive tables and figures.

2.3 Interview Summary

Review of the documentation helped the team develop questions for onsite interviews with USACE and MWI personnel. The interviews and site visits were conducted by Parsons with personnel from the DoDIG office present and were organized with the objectives of understanding the chronology and extent of testing performed, from the initial factory testing through field acceptance testing.

The Parsons team visited the USACE Hurricane Protection Office (HPO) in New Orleans from November 4 to November 7, 2008. During those meetings, details of the design of the pumping facilities, the laboratory testing performed at ERDC, and the testing requirements (which were to be fulfilled by the manufacturer were discussed). The three temporary pump facilities were visited and the team witnessed startup and approximately one hour of pumping at the 17th Street station where all but one of the large hydraulic pumps were operating (one pump was out of service for maintenance).

A visit to the pump manufacturer, MWI, took place November 18, 2008. During that meeting, the details of the factory testing were discussed and a tour of the manufacturer's Deerfield Beach, Florida, test and assembly facilities followed. On November 20, 2008, the Parsons team met with members of the USACE inspection team who were onsite at the pump manufacturer's site during the factory testing of the equipment.

On January 28, 2009, the Parsons team met with the whistleblower at the Palm Beach Gardens USACE office and conducted an interview. During the meeting, information on the extent of tests carried out was discussed together with discussions on pump component performance. Information on factory test methods, outcome of factory tests, and site tests were gathered and recorded at the meeting.

The following subsections summarize the findings of the documentation review, interviews, and site visits.

2.4 Factory Testing

Details of the HPU testing, scaled model, and pump prototype testing performed at the manufacturer's facilities in Deerfield Beach and Sebastian were obtained from the reports provided by the DoDIG and interviews conducted with MWI personnel, the USACE HPO in New Orleans, USACE inspectors from the Jacksonville District and the whistleblower.

Typically, these types of tests are not witnessed by the purchaser as they are identified and resolved by the fabricator before the inspection effort. Furthermore, witnessed events are typically limited to the startup and commissioning of a pump station except in cases where the specifications require witnessed pump and driver testing events.

2.4.1 Factory Testing of the Hydraulic Pumping Units

The equipment specifications called for the HPUs to be pressure tested, both statically and dynamically, at the factory. This testing would provide assurances the units would be operable when they were installed at the site and minimize the commissioning time normally experienced for similar equipment. The testing program originally called for each unit to be tested statically for 90 minutes at design pressure and dynamically for 15 minutes at maximum speed, pressure, and temperature.

In early factory tests, the original cams (66&42) of the Denison pumps on the HPUs were found to be underperforming. These were replaced with 66&50 cams but the performance requirements were still not met due to their lack of ability to continuously operate at the design pressure of 3,200 psi. Dennison replaced all the cams in the HPUs with 72&45 cams at no cost to the government. The available data indicates that all HPUs onsite today have the 72&45 cams installed and have proven to operate successfully. MWI recommended operating the pumps with a design pressure of 3,200 psi.

As documented in other reports, some component failures occurred during the factory tests. The subject components were repaired or replaced and tests resumed.

Recognizing the critical schedule constraints to have the pumps on site, ready to operate in the hurricane season, delivery schedules and tests were modified during the course of the testing. Test requirements were modified to drop initial performance testing of each of the water pumps and test all the HPUs for a minimum of 3 hours at full speed, fully loaded. Records that track each equipment number through the testing process show all 40 HPUs went through a 3-hour acceptance test at the factory. Each unit under test was connected to a hydraulic water pump in a water tank and tested for its maximum driving pressure. One HPU experienced engine abnormalities and did not pass the 3-hour acceptance test. This unit was however shipped to the field without the Government's approval of testing. USACE made a decision to allow corrections to be made to the unit in the field rather than sending it back to the factory. This unit passed the field acceptance test and logged 25 running hours.

2.4.1.1 Findings

While there are standards related to the hydraulic performance of pumps of this type, there is no industry standard for the factory testing of the drive units and pumps during the manufacturing process. The testing performed early in the manufacturing process of the HPUs proved beneficial in that it identified assembly and performance abnormalities in the drive units that significantly reduced the time spent on acceptance and commissioning after the pumps were installed onsite. Abnormalities encountered with the HPU configuration were identified and corrected, resulting in more reliable pieces of equipment. The abnormalities encountered during the performance tests of the HPUs were addressed. Recognizing critical test items and delivery dates were at risk, the USACE officials modified the test procedures in the course of production but did additional field testing to ensure pump operation and endurance.

2.4.2 Factory Prototype Performance Test

A factory prototype test was also performed (November 2006) to measure the performance of a full-scale prototype pump and compare it to the design requirements. This performance test was performed and observed by USACE. The report, which was reviewed for this evaluation, is titled "Data Report on Factory Tests of Discharge and Total Dynamic Head of MWI Pumps used on New Orleans Outfall Canals," December 2006.

2.4.2.1 Flow Measurements

The ERDC report indicates numerous difficulties in getting consistent readings with the test setup to measure flow. Due diligence was exercised by the investigator to minimize the error related to velocity differences in the discharge piping at the point of flow measurement by taking extensive cross-sectional measurements and using accepted standards to correct the data (United States Bureau of Reclamation [USBR] Water Measurement Manual). The flow measurement points are shown in Figure 2-3. The collected data was corrected using standard procedures to account for the differences in test operating speed so comparisons could be made with the contract requirements and a previous test noted as "Measured MWI Analysis-288 rpm."

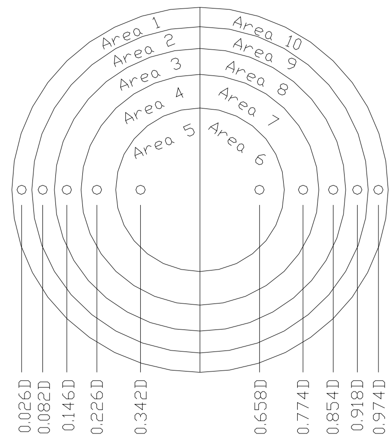

Figure 2-3—Flow Measurement Points

> USBR 10-pt Velocity Traverse. D = pipe diameter. The dimensions are extracted from the "Data Report on Factory Tests of Discharge and Total Dynamic Head of MWI Pumps Used on New Orleans Outfall Canals."

The prototype test data collected was then plotted on the curve of the previously collected MWI prototype data, as shown in Figure 2-4, with a difference found in the slope of the curves. The Measured ERDC Analysis – 288 revolutions per minute (rpm) test curve is parallel but lower than the Measured – MWI Analysis – 288 rpm, suggesting there may be a difference in the method of velocity calculations.

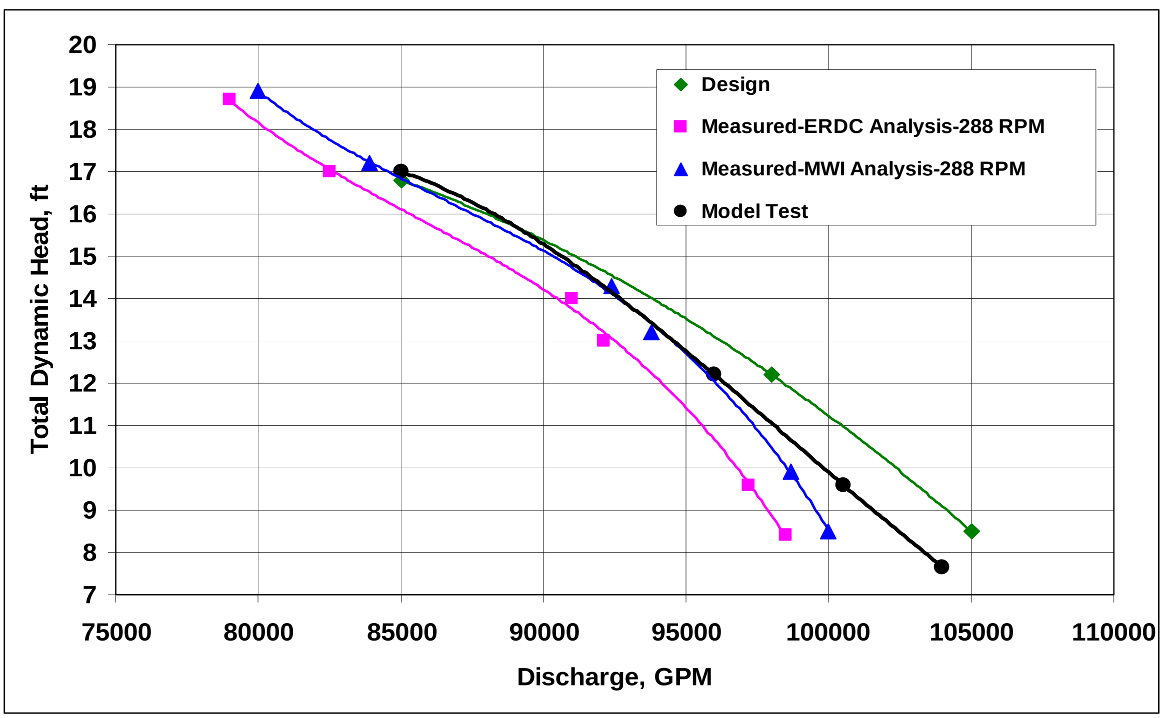

Figure 2-4—Head-Discharge Curves Design

Figure 2-4 shows head-discharge curves design, measured with ERDC analysis and with MWI analysis, the discharge is based on the average of all 4 traverses.

2.4.2.2 Findings

The size of these pumps necessitated a very large quantity of water in order to run a full test. The water was pumped from a sump and was continuously recirculated through the test set up for the duration of the test. The sump size available at the manufacturer's facility made it difficult to achieve the desired conditions to obtain the flow data, since the smaller sump size resulted in turbulence, aeration, and elevated water temperatures for the recirculated water, all of which can adversely impact the results. Because of these types of abnormalities in testing pumps of this size, it is not uncommon within the industry to gather the performance data from a scaled model rather than from a full-sized pump. It is the opinion of the Parsons team that results from the factory prototype pump test are not reliable to accurately predict flow rates.

2.4.3 Factory Scaled Model Test

At the request of the USACE HPO in New Orleans, ERDC was requested to observe and assist with testing a scaled model (with a ratio of 1:3.75) of the MWI pumps. This test was performed to compare the measured discharge total dynamic head of the scaled model pump with the design values for the prototype pumps, and then extrapolate that data to predict the performance of the prototype pumps. The report reviewed for this portion of the evaluation was "Draft Data Report on Factory Model Tests of Discharge and Head of MWI Pumps Used on New Orleans Outfall Canals," September 2007.

2.4.3.1 Test Setup

The following are the details given in this report that were checked with ANSI/HI standards contained in ANSI/HI 2.6-2000:

1. Discharge pressure tap: The location of the pump_discharge pressure tap is consistent with the dimensions required by ANSI/HI Figure 2.85, page 29.
2. Flow meter location: Distance from pump discharge head fittings is greater than the minimum required by ANSI/HI Table 2.14, page 26 for a throat/inlet diameter ratio of 0.718 therefore acceptable.
3. Throttling Valve Location: The distance from the Venturi to the valve is more than sufficient per ANSI/HI Table 2.16, page 27.
4. Return to Sump: The discharge is below the water surface to prevent aeration. Turbulence generated against the bottom can not be determined.
5. Interior Sump Box: The report states that the interior sump box was based on acceptable sump design in the ANSI/HI standards. Assuming a model pump bell of 25.1 inches (full-size bell diameter of 7.85 ft divided by the model scale of 1:3.75), the length of the sump box was shorter and the width was slightly narrower than that recommended in ANSI/HI 9.8-1998 Standard for Pump Intake Design. The potential impact of the deviations is that some swirl may form in the intake that could influence the head or flow measurements, but such influence would be minor.

2.4.3.2 Instrumentation

1. Mercury manometer: A common instrument used in the industry for accurate differential pressure readings and is identified in this report for measuring static head.
2. Venturi flow meter: This is a typical, accurate flow measuring device of sufficient dimensions to give accurate readings. There is no indication in ERDC's report as to the differential pressure device used to take readings. The report indicated Alden Research Lab had performed a calibration of the instrument, but the calibration report was not included with ERDC's report nor was the date of calibration noted.
3. Tachometer: A laser, hand-held tachometer was used and readings checked against a second tachometer. No calibration data were noted for either instrument; however, the readings from each instrument checked against each other.
4. Torque Measurement: This is also a common means of measuring input power. Calibration data is included in the report but no original document with the date of calibration was included. ANSI/HI requires torque meters be calibrated within certain intervals. It is the opinion of the Parsons team that the omission of this data probably will have minimal affect on the results.

2.4.3.3 Findings

The test setup and instrumentation used for the scale model were consistent with ANSI/HI standard tests, with the exception of the size of the sump box as noted above. The documentation provided for the test did not include all the detailed data described in ANSI/HI standards, page 14, "Summary of Necessary Data on Pumps to be Tested," but the details are referenced in the ERDC report.

A check of the data recorded in the report showed the model pump efficiency to be calculated correctly. The model test data is then extrapolated to what can be expected from the prototype based on the affinity laws. The efficiency calculations assumed an exponent of 0.26 for the formula. This conservative and acceptable number is related to the casting roughness of the model compared to the prototype. The report did not include the predicted horsepower requirements for the prototype, but it has been calculated and added to Table 2-1 below.

The predicted horsepower is important to determine the requirements for the hydraulic drive system and sizing of the engine power supply for the full-size equipment. Data on the efficiency of the hydraulic drive system was provided by MWI. The Parsons team used the efficiency data, as published by the component manufacturers and compared this data to the required HP. The results of this evaluation verify the adequacy of the components.

Table 2-1—Predicted Pump Horsepower

Test	Prototype Q[a] based on affinity laws, gpm	Prototype TDH[b] at 288 rpm based on affinity laws, ft	Prototype pump efficiency, Percent (%)	Prototype pump horsepower, HP
10	64914	22.54	74.4	497
11	81174	18.41	78.5	483
12	85059	16.95	78.3	467
13	96448	12.1	74.4	399
14	100683	9.26	68	348
15	104367	7.59	64.1	313

[a] *Q is flowrate*
[b] *TDH is Total Dynamic Head*

Ref: Draft Data Report on Factory Model Tests of Discharge and Head of MWI Pumps Used on New Orleans Outfall Pumps, Table 3, September 2007.

2.4.4 Hydrostatic Tests

The water pump units were tested hydrostatically for 90 minutes to check for leaks. The process included raising the pressure in the high-pressure plumbing (hose) and the pump head to 3200 psi while restraining the propellers with wood blocking to induce the test pressure. Hydrostatic test data from a Jacksonville QA report indicates that all static tests conducted on the pump units successfully met the specified requirements.

2.4.4.1 Findings

All of the pump casings passed these tests. Records show some pumps tested were not initially successful and that these pumps went through corrections and further testing. The types of malfunctions noted in the reports during equipment testing are considered normal in an industrial manufacturing environment. The Parsons team's opinion is that the pumps were conclusively tested to an acceptable operational standard.

2.5 Field Testing

The field testing of the pumps was divided into performance, acceptance, and endurance testing. All field testing occurred at the three pump stations in New Orleans.

2.5.1 Performance Testing

Performance testing was performed in the field to measure the flow capacity of the pumps during operation. Parsons conducted a review of each field test by comparing the test data to the calculated performance of the system. The calculations were completed by Parsons using the installation drawings to determine pipe lengths, number of elbows, and elevations. Parsons did not conduct a detailed evaluation due to limited actual installed pump system head and flow data that would allow verification of the theoretical system curves.

2.5.1.1 17th Street Canal Pump Station

The report reviewed was "Draft Data Report, Field Study of Pump Discharge and Head at 17th Street Canal Interim Pumping Station," May 2007.

The flow determination of the field tests is dependent on the operating head of the system. In general, the system curve (head versus flow) for pumps that have a low operating head is quite flat. Each pump was fitted with piezometers to measure the head produced by each pump. No reading was taken on the manifold so it did not facilitate comparison of system pressure with the system flow readings from the acoustic flow meters on the manifold. The pump curve performance noted in the report does not include the operating rpm that the accuracy could not be checked when plotted on the system curve. It is the opinion of the Parsons team that these results of the field testing for the 17th Street Canal temporary pump station does not provide confirmation of the capacity of the pumps, but does provide an approximate capacity that is acceptable.

2.5.1.2 Orleans Avenue Canal Pump Station

The report reviewed was "Draft Data Report, Field Study of Pump Discharge and Head at Orleans Avenue Canal Interim Pumping Station," May 2007.

The performance data collected for Pumps W5-1 and W5-3 that were on the same three pump manifold indicates which pump discharge head was approximately 2 feet off the theoretical system curve. The performance data collected for Pumps W5-4 and W5-5 that were on a two pump manifold identified which of the air vacuum breakers did not seal and allow for full prime of the siphons. Therefore, the pumps ran at a higher head than would be expected. On this basis, this test provides approximate data. It is the opinion of the Parsons team that these results of the field testing for the Orleans Avenue Canal Interim Pump Station do not provide confirmation of the capacity of the pumps, but does provide approximate capacities of the pumps that is acceptable.

2.5.1.3 London Avenue Canal Pump Station

The reference report was "Draft Data Report, Field Study of Pump Discharge and Head at London Avenue Canal Interim Pumping Station," July 2007.

The pump curves plotted were from the model test and prototype test data corrected from 188 rpm. Data plot matches the corrected model test data curve, but the head was significantly higher than the theoretical system curve. However, data from three different measuring systems did not correlate with any of the curves. Some of this may be due to the lack of pressure head readings on the manifold where the flow readings were taken. It is the opinion of the Parsons team that these results of the field testing for the London Avenue Canal temporary pump station do not provide confirmation of the capacity of the pumps, but does provide approximate capacities of the pumps that is acceptable.

2.5.1.4 Findings

The field performance tests at each of the pump stations used at least two methods of flow measurement, but the London Avenue station appears to have used four methods. One of the methods used on all three stations was piezometer head readings transferred to the prototype test performance curve to determine flow. This data method is approximate since there was no way to accurately determine impeller rpm. Thus, the field tests can be considered as representing the approximate capacity these stations can produce.

Two Rineer motors experienced pulsating activity while running the pumps on site. Investigations revealed there was a problem with inadequate stiffness of the springs in the motors. Once those springs were replaced, the pulsating issue was resolved. All of the Rineer motors onsite today have the new springs installed. Inspection of these motors should be part of the normal maintenance activities at the stations so if any wear is noted, it can be addressed.

2.5.2 Acceptance Testing

The field acceptance tests for each complete system included running at least 2 hours at an engine speed of 1,800 rpm and a hydraulic pressure of 3,200 psi. Steady-state conditions, engine rpm, engine jacket temperature, hydraulic system oil pressure and temperature, leakage (required: none), and canal level were monitored. These tests were conducted on each hydraulic pumping system by the contractor with oversight by USACE. USACE documented any deviations from the testing parameters including pump speeds, run times and temperatures.

The documentation showed all abnormalities previously identified in the pump manufacture and installations were corrected prior to the acceptance tests. All HPUs were fitted with new cams on site in July 2006 prior to acceptance tests. Reports by USACE showed that acceptance inspections started in June 2007, and included punch lists for the drive units noting the physical abnormalities to be corrected. Most abnormalities were corrected by September, 2007, with a few minor issues still noted in the punch list for the drive units. A review of the acceptance test results of the pumps follows.

2.5.2.1 London Avenue

Acceptance tests for the London Avenue Canal pumps started in July 2007. The test results indicate that fully loaded run tests were performed on 12 pumps at the site. Out of the 12 pumps tested, 9 pumps passed the initial acceptance tests. Functional abnormalities such as oil leaks, high oil temperature, and overheating gear oil caused the 3 pumps to fail the initial tests. These abnormalities were corrected and the 3 pumps then passed the running test as shown on the pump acceptance log, dated November 2007.

2.5.2.2 Orleans Avenue

Acceptance tests for the Orleans Avenue Canal pumps started in June, 2007. Functional abnormalities, including a damaged seal, leaking bearing o-ring and underwater oil leaks, occurred with 3 pumps. These abnormalities were corrected by August, 2007 and the pumps were re-tested. All passed the running test as shown on the pump acceptance log, dated November, 2007.

2.5.2.3 17th Street

Acceptance tests for the 17th Street Canal pumps started in August, 2007. The test logs of September, 2007 indicate 10 out of 18 pumps underwent the fully loaded test and all 10 pumps passed. No functional abnormalities occurred with these ten pumps. The remaining 8 pumps were tested by September, 2007 with all 8 pumps passing. Quality

Assurance Reports show that due to low canal levels, some pumps were run at reduced speeds of 1400 rpm and some pumps were tested for shorter periods of 1.5 hours during pump tests. These pumps were, however, also deemed to have passed the acceptance tests by the USACE Quality Assurance Team because performance was demonstrated upon reaching 45 minutes of steady state conditions.

2.5.2.4 Findings

All 40 pump systems were finally accepted. It is the opinion of the Parsons team that there was due diligence in the inspection and correction of any functional abnormalities throughout the testing. Abnormalities encountered were normal to the commissioning and startup of this type of equipment.

2.5.3 Endurance Testing

An endurance test was performed on a drive unit at the London Canal. This test used a HPU mounted to the bridge upstream of the flood gate with a spare pump mounted to the temporary sheet pile structure. This temporary sheet pile structure was installed as a contingency plan pending completion of the temporary pump station. During the initial attempts to run the test, functional abnormalities with the drive unit had to be corrected. Once those corrections were made, the HPU successfully completed a total of 37 hours, 29 minutes of operation.

2.5.3.1 Findings

The evaluation of the endurance test report showed that there were three attempts to run the endurance test. Typical startup abnormalities were encountered with the first two attempts. On the third attempt the pump successfully performed without incident.

2.6 Laboratory Physical Sump Model Testing

A pump of this size and type can be sensitive to the approach flow hydraulics, and keeping with ANSI/HI standards, the HPO engaged the USACE ERDC in Vicksburg, MS, to conduct a physical model study of the Interim Pumping Stations at both the London Avenue Canal and 17th Street Canal. No physical model study was conducted of the Orleans Avenue Canal's pump station sump, as ERDC determined the modifications developed for the London Avenue Canal would be effective at the Orleans Avenue Canal's temporary pump station because the approach canal layouts were similar. The intake modifications which were developed for the London Avenue station were replicated at the Orleans Avenue station.

Two reports were developed for the physical model studies. The first report, "Physical Model Study of Interim Pumping Station at London Avenue Canal, New Orleans, Louisiana," dated January 2008 covers the study performed for the London Avenue Canal station. The second model study covered the 17th Street Canal station and is titled "Physical Model Study of Interim Pumping Station at 17th Street Canal, New Orleans, Louisiana," January 2008. The model studies were used to evaluate the potential for surface and subsurface vortices, flow pre-swirl entering the pumps, and the velocity distribution at the pump impeller location. The Parsons team reviewed the model studies with ERDC in New Orleans in November 2008.

The review of the report and meeting are summarized in the following subsections.

Typically, the sump model studies are conducted as part of the design of the station and HI states that for stations of this size and criticality they are required. Due to the very rapid timeline associated with this installation, the conventional timelines associated with physical models of pumps were not able to be accommodated; therefore, ERDC conducted the model study after the pumps were installed and operating at the site. The modifications that were developed as a result of the model testing were then subsequently installed at the London Avenue and Orleans Avenue pump stations.

2.6.1 Model Scale

The selection of model scale is based on minimizing the fluid viscous effects (Reynolds number) and surface tension effects (Weber number). The model scale that was selected for these pumps, 1:15, resulted in a pump bell Reynolds number of 6×10^4, which meets the HI criterion. This scale also satisfied internal ERDC criterion. No mention was made in the report of whether a 1:15 scale model met the Weber number criterion; however, Parsons team calculations determined that it was acceptable.

2.6.2 Model Layout and Extent

The models for the two stations included all pumps (hydraulic and direct drive), pump platforms, and support structures that were in the water. The model pump bells simulated the prototype pump bells. Approach channels, 1,100 feet for London Avenue, 840 feet for 17th Street, were simulated in the models. The canal widths of 360 feet and 240 feet respectively for the London Avenue and 17th Street Canals make the approach channels somewhat short, but since the canals are relatively straight upstream of the pump stations and an overflow weir was used at the upstream end of the models, the model length is acceptable. The only issue that was noted was the flow over the model weir caused surface turbulence that in fact could inhibit the formation of surface vortices which may occur in the prototype, resulting in less conservative results.

Flow calibration of the individual model pumps followed generally accepted practice.

Canal bathymetry (a study of underwater depths), to measure depths of the canal, was developed using gravel. This was used to simulate the canal roughness since the canal in the area of the pump station was protected with rock; therefore using gravel to simulate roughness was a reasonable approach.

2.6.3 Test Conditions

Since there are no test standard requirements to assist with determining the critical pump operating combinations, professional judgment was used. ERDC decided to conduct three test conditions, which were as follows: (1) all pumps operating (hydraulically driven and direct drive); (2) all hydraulic drive pumps operating; and (3) all direct drive pumps operating. In addition, for the 17th Street station, a fourth condition was tested, which consisted of all the MWI hydraulically driven pumps and the portable pumps on the interim gated structure, which were providing an additional 1400 cfs capacity. More typical operations when fewer pumps are operating were not simulated with the models, but it was the opinion of ERDC that the most extreme operating condition is when the stations are running at full capacity. This may be a non-conservative opinion since the worst approach flow hydraulics can occur when fewer pumps are operating. For example, the water surface was turbulent during the model tests which could have inhibited the formation of surface vortices. With less pumps operating, the water surface in the model will be more tranquil which is conducive to the formation of surface vortices. With more pumps operating, the approach velocities are higher which may wash out subsurface vortices. Again, with less pumps running, the approach velocities will be less and may allow for subsurface vortices to become stronger and more stable.

2.6.4 Instrumentation

The instrumentation used in the model studies followed normal laboratory procedures and ANSI/HI standards. The velocity fluctuation data at the pump impeller location was not taken (discussed below). Swirl meters were installed according to ANSI/HI standards and flow velocities were taken at several locations which were selected based on high flow pre-swirl readings. This is normal practice.

2.6.5 Acceptance Criteria

The acceptance criterion was discussed at length, with ERDC accepting a relaxed HI standard due to “infrequent pump operating conditions” (see ANSI/HI standards criteria for “infrequent pump operating conditions” as stated in the ERDC January 2008 Report). The infrequent operation conditions that the HI discusses are usually associated with a station operating under abnormal conditions. During normal operation the station should meet the stricter criteria. The interpretation used by ERDC is that since these stations only operate infrequently, the use of the relaxed standards for “infrequent pump operating conditions” was appropriate. In addition, ERDC only conducted tests at extreme flow conditions and more frequent operating conditions were not analyzed. It is unknown whether the pump stations would meet the stricter criteria for more normal operations. Since a scale model is nonconservative related to the formation of surface or subsurface vortices due to viscous effects, applying the more relaxed HI standard associated with infrequent operation could result in vortices entering the pumps that have a low enough pressure to result in vibration, cavitation, and bearing wear.

One HI criterion related to measuring time-varying velocities at the pump impeller location was not evaluated due to time limitations and the fact that ERDC rarely takes these measurements. The time-varying velocity measurement can pick up excessive velocity fluctuations that could result in flashes of cavitation and bearing wear. However, research has indicated that exceeding the criterion does not normally result in significant pump performance issues.

HI also states that a few tests with the final design should be conducted at 1.5 Froude scaled flow rates. The Froude number is defined as the characteristic velocity divided by the water wave propagation velocity. This will compensate for any possible scale effects on free-surface vortices. However, when it is determined the flow patterns are too distorted to provide a reasonable analysis, it is not necessary to perform these tests. In this case these tests were not performed for this reason.

The ERDC report states that one rationale used for accepting the relaxed standards is based on satisfactory prototype test results of a one day test which was conducted in the field in April, 2007. During these field tests, the formation of surface vortices were observed. A scale model test was conducted with the same operation scenario and indicated that both surface and subsurface vortices formed and that flow pre-swirl occurred in excess of acceptable levels.

It should be noted that experience indicates that almost all the hydraulic issues associated with poor approach flow hydraulics do not cause instantaneous abnormalities. Typically, the effect of surface and subsurface vortices, along with pre-swirl conditions, results in vibration damage, cavitation damage, and bearing wear over a period of time of use.

2.6.6 Test Results

Based on the modified HI performance criteria, it is Parsons team's opinion that the model studies were conducted in accordance with accepted engineering standards. Modifications to the sump designs were developed using the models. For the London Avenue station, the modifications to reduce swirl consisted of the installation of a sump floor cone with 4 vanes that were attached to the pump bells and hung below the bells to within a maximum of 6 inches above the sump floor. In addition, a surface vortex grate was installed horizontally just below minimum water level to address submerged vortex concerns. These same modifications were installed at the Orleans Avenue pump station.

For the 17th Street pump configuration, the modifications identified by the model included lengthening the pump bays (for west and east side 6 pump platforms) and installing grating at the entrance to turn the flow into the pump bays. No modifications were developed to control submerged vortices since they were considered weak. However, experience shows the vortices should be monitored and the pumps inspected according to a regular maintenance program to ensure that there are no signs of impeller or bearing deterioration.

2.6.7 Implementation of the Modifications to the Prototype Structures

It is the Parsons team's understanding that the modifications identified during the model testing have been installed at the London Avenue station and duplicated at the Orleans station. For the 17th Street pump station, the modifications that were developed on the model were not implemented in the field due to the extent of the modifications identified. There is ample redundancy at this station and other pumps can be brought on line if there are abnormalities with some of the pumps. The redundancy also allows for the operating sequence that rotates the cycle time on the pumps.

2.6.8 Findings

The sump model studies for the London Avenue and 17th Street Canals' interim pump stations generally met ANSI/HI standards. The performance criteria that were not evaluated or were relaxed may have an impact on the performance of the pumps; however, it is the opinion of the Parsons team that the modifications that were developed in the model should minimize any effect, especially if a thorough inspection and maintenance program is followed.

Not constructing and installing the recommended modifications at the 17th Street station may result in performance issues, such as cavitation, vibration, and bearing wear. It is recommended that the pumps be inspected for unusual wear as part of a regular maintenance program. If there are signs of deterioration, then the recommended modifications from the model study could be implemented to improve pump performance and longevity.

Although the Orleans Avenue station, which includes the modifications developed for the London Avenue station, should perform satisfactorily, this station has no backup system (i.e., direct drive pumps nor excessive flow capacity). To confirm the design, a model study could be conducted to verify the effectiveness of the modification. As an option, the pumps at this station could be monitored for vibration and pulled and inspected for wear as part of a regular maintenance program.

2.7 Conclusions

It is the Parsons team's opinion that the scale pump testing at the factory, and the sump model testing for the 17th Street and London Avenue Canal Interim Pump Stations, are adequate for their intended purpose. The scale pump test should be considered the definitive test. No additional pump testing is required. For the Orleans Avenue Canal Interim Pump Station, a pump sump physical model study was not conducted as specified by HI.

2.7.1 Factory

The testing performed on the pump systems is in line with industry standards. Abnormalities identified during the testing, both at the factory and in the field, were satisfactorily addressed. Additional testing was performed in the field to verify the pump performance.

Due to the accelerated procurement schedule, acceptance testing at the factory was started prior to the manufacturer being able to troubleshoot the equipment set up, resulting in the onsite inspectors observing an increased number of incidents with the equipment. Usually the manufacturer has had time to set up a system and perform a mock test to ensure that the equipment will perform as anticipated when the inspectors arrive. The testing of each drive unit at the factory proved very valuable in that abnormalities in the cams and other mechanical components were able to be identified and corrected before the field testing occurred, greatly reducing the amount of time normally associated with commissioning and acceptance testing.

Full-size testing of pumps of this size is not usually required, as a model is normally used to obtain performance parameters for such large pumps. The testing of each individual pump in the factory is above what is normally specified, too, since all the pumps are manufactured to the same specifications and will, therefore, have little change in performance from pump to pump.

With regard to pump capacity, it is the Parsons team's opinion that the use of the scaled model test, extrapolated to predict the performance of the prototype pump is a better representation of the pump capacity than the prototype pump testing results that were witnessed by ERDC.

Despite the anomalies witnessed during these factory tests, the Parsons team's opinion is that the factory testing was adequate for its intended purpose and the response to correcting the failures indicates diligence was exercised. Additionally, the field testing to verify satisfactory performance supersedes the events witnessed at the factory.

2.7.2 Field

The acceptance and endurance testing in the field was performed in general conformance with industry standards. The anomalies experienced during the acceptance testing are consistent with the types of anomalies normally experienced during the startup phase of permanent pump stations designed and constructed for USACE. Correction and retesting is typically administered until the witnessed anomalies are eliminated and there are no other anomalies experienced. The acceptance testing documentation indicates consistency with this industry standard.

2.7.3 Laboratory

The laboratory testing was in general conformance with the applicable ANSI/HI standards. The report discusses the acceptance criteria used for the evaluation of the test results. The temporary pump stations at the subject canals are unique in that their required use is only during those design rainfall events during which Lake Pontchartrain experiences storm surge. This interpretation versus the more strict interpretation of "infrequent pump operating conditions" has a material effect on the determination of whether the observed vortices during the model tests are acceptable or not. Regardless of the interpretation, the consequences of the approach hydraulic conditions observed are typically time dependent for any substantive mechanical degradation. Moreover, these tests are typically conducted in advance of construction to provide an opportunity to modify pump conditions before the construction activities. The emergency response for construction did not lend itself to this typical sequencing.

Section 3 – Vulnerability Analysis

3.1 Purpose

An assumption in a vulnerability analysis is that mechanical systems are inherently vulnerable to breakdowns. The purpose of this effort is not to predict the absence of future breakdowns, nor to predict timing of future breakdowns, but rather to identify any conditions that would indicate extraordinary and unacceptable vulnerabilities leading to flooding of areas to be protected by the temporary pumping facilities. Equipment failures are inherent. Excessive equipment failures and lack of ability to accommodate normal failures are unacceptable vulnerabilities. The Parsons team's investigation indicates that planning, design, equipment procurement, and construction for project delivery were conducted under extreme conditions. The planning, design, procurement, construction, installation, and acceptance of over 16,600 cfs in pumping capability in a period of approximately 21 months required substantial deviation from normal procurement, design, and construction protocols. Substantially witnessed abnormalities of the pumping systems were observed during the fabrication and assembly processes. As discussed in previous sections these types of tests are not typically witnessed by the purchaser as they are identified and resolved by the fabricator before the inspection effort. Therefore, the observations by the witnesses during fabrication are considered in-progress observations. Witnessed underperformance and the resolution of those conditions were considered in this report. The Parsons team's vulnerability analysis focuses on the final configuration and performance records of the system as it currently exists at all three canal outfall locations, which is a better indication of actual vulnerability of the system.

The vulnerability analysis was conducted to identify extraordinary conditions of the hydraulic pumping systems and their supporting systems that might indicate a vulnerability of failure above and beyond those that are inherently associated with electro-mechanical systems as applied under conditions of similar risks and consequences of failure. Special consideration was given to conditions that might lead to under-performance of the system during emergency response events. The scope and assumptions for the vulnerability analysis is as follows:

- The temporary pump stations are designed for a 5- to 7-year service life because they will be replaced with permanent pump stations by 2013.
- It is assumed that USACE will maintain the canals at their designated safe level in coordination with the SWB.
- The pump stations are manned during a storm and hurricane event.
- This vulnerability analysis does not include analysis of risks related to canal levels, flooding risks, flood walls integrity, and any other risk factors that do not relate to the outfall canal temporary hydraulic pumping systems.
- Design and construction information was obtained from specifications, design and construction drawings, and information received during interviews as outlined below in Section 3.2. Methodology.

3.2 Methodology

This section outlines the methodology used to analyze potential vulnerabilities. The Parsons team conducted this assessment by evaluating the available documents and conducting interviews with the appropriate agencies and individuals with regard to the pump material/component assessment, structural considerations, electrical and instrumentation systems, and hydraulic considerations. After the interviews and site visits, the Parsons' team met to develop a list of "what ifs." The objective of this brainstorming meeting was to develop a list of threats to the hydraulic pumping systems and their supporting systems with the goal of determining potential vulnerabilities of the system under analysis. Through this process, the Parsons team prepared a database of information that was analyzed to determine the degree of vulnerability utilizing common engineering practice. This process takes into account both the category of vulnerability and the category of criticality of the asset or condition being analyzed. (Refer to Table 3-1, shown below.) The distinction of these two elements are summarized and illustrated as follows:

- **Vulnerability Category:** The degree to which the element being analyzed is vulnerable. This category has three degrees of measure—extreme, moderate, and slight, which are labeled a, b, and c respectively.
- **Criticality Category:** The degree to which the element is considered critical to operational readiness. This category has three degrees of measure—high, medium, and low, which are labeled 1, 2, and 3 respectively.

Table 3-1—Criticality

Categories of Vulnerability	**Categories of Criticality**		
	1 – High	2 – Medium	3 – Low
a - Extreme	1a	2a	3a
b - Moderate	1b	2b	3b
c - Slight	1c	2c	3c

The Asset Risk Level is therefore determined as shown below in Table 3-2:

Table 3-2—Asset Risk Levels

Asset Risk Levels			
1a	2a	1b	High-Level Priority items to address
1c	2b	2c	Mid-Level Priority but Agency may accept
3a	3b	3c	Low-Level Priority acceptable to Agency

The following actions were conducted to evaluate the vulnerabilities of the outfall temporary hydraulic pumping systems and their support systems.

- Conducted assessments from early November 2008 through December 2008. The Parsons team reviewed specifications written for the procurement of the pumps, the construction documentation, factory tests records, and performance requirements.

- Interviewed the USACE project officials on November 4, 2008, at the New Orleans District, and the canal operation staff.
- Visited the sites from November 4 to 5, 2008, of the three temporary pump stations at 17th Street, London Avenue, and Orleans Avenue, and examined components of the pumps, pump drives, electrical distribution, and control including the hydraulic driven gates.
- Observed the hydraulic pumps running at the 17th Street pump station on November 4, 2008, and interviewed operational staff.
- Visited the New Orleans SWB Pump Station Number 6, on November 5, 2008, to observe operations and to interview operational staff. Interviewed the SWB Superintendent and staff.
- Interviewed ERDC on November 6, 2008, on the modeling of the pump station and attended a presentation by ERDC followed by a question and answer discussion on the science of his methods of modeling.
- Visited the factory facilities of the pump manufacturers MWI on November 18, 2008. Met with production management and the chief mechanical engineer and conducted interviews with each individual.
- Interviewed the USACE Jacksonville District inspecting officials on November 20, 2008, regarding the pump testing procedures. We discussed their observations, their records, and their opinions of the testing of the pumps and pump drives.
- Held brainstorming sessions between November 8 and 28, 2008, with Parsons professional engineering team regarding the vulnerabilities to failure of the temporary hydraulic pump systems and their supporting systems.
- Conducted follow up interviews with the USACE staff in New Orleans on December 2 and 3, 2008. This session focused on the USACE equipment preventive maintenance program in place and additional discussions on the acceptance testing timeline.
- Interviewed the USACE whistleblower on January 28, 2009, regarding the pump testing procedures. Discussions were held regarding the whistleblower's observations, records and opinions of the pump and pump drive testing.

3.3 Findings in Brief

The vulnerability analysis was conducted considering structural, mechanical, electrical, maintenance, and operational aspects of the hydraulic pumping system including its support systems. As stated in subsection 3.1, Purpose, this effort is intended to identify what, if any, extraordinary vulnerabilities exist for the hydraulic pumping systems and its supporting systems. In summary, it is the Parsons team's opinion that the hydraulic pumping systems and their support systems do not exhibit unusual or extraordinary vulnerabilities. Table 3-3 indicates the vulnerabilities identified and their assessed risk level as determined through the previously described methodology and Table 3-1 and Table 3-2.

3.4 Component Vulnerabilities

3.4.1 Findings

This section identifies any components of the temporary pump stations and their support systems that are vulnerable to failure before, during, and after a storm event.

Table 3-3—Component Vulnerabilities

Source or Cause of Potential Vulnerability	Affected Pump Stations			Assessed Categories	
	17th Street	Orleans	London	Criticality	Vulnerability
Protection of exposed hoses engines of hydraulics, electrics and batteries from wind borne debris, projectiles	x	X	x	3	b
Power poles next to diesel tanks	x			3	b
Elbow fittings Aeroquip - leak issue	x	X	x	2	c
Unsuitable CCTV camera mountings	x	X	x	3	c
Vapor proof lighting in the pump area and under the pump deck	x	X	x	3	c
Unpainted hydraulic oil piping	x	X	x	2	c
Unsuitable pole mounted light fixtures	x	X	x	3	c
Criticality: 1 – High; 2 – Medium; and 3 – Low Vulnerability: a – Extreme; b – Moderate; and c – Slight Note: Refer to Tables 3-1 and 3-2 for more information.					

- **Protection of exposed hoses of hydraulics. Electrics and batteries from wind borne debris and projectiles:** The team identified that these components are vulnerable, but they are not detrimental to the overall operation of the pump stations. This vulnerability is rated low on the scale of priorities for improvement.
- **Power poles next to diesel tanks:** A power pole was found erected next to one of the main fuel storage tanks. The pole carries a 4,160 volt step-down transformer to feed the 17th Street Canal temporary outflow pump station. The fuel tank is in the path of the pole falling radius. The team rated this issue as a low criticality, but it has an average rating of vulnerability.
- **Aeroquip elbow fittings leaks:** This item is inserted into the vulnerability matrix with the intention that this issue be kept in view until resolved by the manufacturer.
- **Unsuitable closed circuit television (CCTV) camera mountings:** The camera mountings are attached to the poles using large hose clips. These hose clips are not hurricane rated. U-bolts are typically used to secure the cameras subject to

high wind conditions. The concern here is that the cameras could come loose in a hurricane event and damage critical parts of the hydraulic pumping system.

- **Vapor proof lighting fixtures in the pump area and under the deck are not impact resistant:** The electrical lighting was examined, and it was noted that the lighting fixtures underneath the engine platforms were of the vapor proof fluorescent type fixtures. These fixtures are for wet areas, but they are not designed for hurricane force conditions. Therefore, they could potentially fall and destroy critical components of the pump.

- **Unpainted hydraulic oil piping:** This item is inserted into the vulnerability matrix with the intention that this issue be kept in view until resolved by painting protective coatings on the piping. It was determined that the pipe manufacturer test coupons as well as the mill test certificate American Petroleum Institute (API) listing showed that the pipe supplied exceeded Grade B pipe strength values.

  Parsons conducted an independent calculation of the piping thickness required. This analysis was based on the requirements as outlined in ANSI B31, 31.3 as applicable for 3,200 psi and a corrosion value of .02 inches which translates to 4 or 6.67 microns per year for a 5- and 3-year project life respectively. It is the Parsons team's opinion that this rate of corrosion is consistent with the industry standards used to predict corrosion rates given the existing exposure. Nevertheless, it is also the Parsons team's recommendation that the pipes receive appropriate protective coatings to ensure that corrosion is controlled throughout the life of the temporary pump station.

- **Unsuitable pole-mounted light fixtures:** The pole-mounted light fixtures along the bridges and walkways designated Type F6 in the construction drawings are not designed for hurricane force conditions; therefore, they could fall and destroy critical components of the pump.

3.5 Operational Vulnerabilities

3.5.1 Findings

This section identifies parts of the operation and process that are vulnerable to the successful operation of the temporary pump stations and their support systems.

Table 3-4—Operational Vulnerabilities

Source or Cause of Potential Vulnerability	Affected Pump Stations			Assessed Categories	
	17th Street	Orleans	London	Criticality	Vulnerability
No Alarms on the hydraulic drives for over pressure	x	X	x	3	c
Orleans Avenue Canal pump station sump design		X		2	c
17th Street Canal pump station sump design	x			2	b

Criticality: 1 – High; 2 – Medium; and 3 – Low
Vulnerability: a – Extreme; b – Moderate; and c – Slight
Note: Refer to Tables 3-1 and 3-2 for more information.

- **No alarms on the hydraulic drives for over pressure:** The team observed that there were no hydraulic oil over-pressure alarms. There are pressure safety valves in place to relieve the hydraulic oil over pressure but there are no alarms or visual indication when this safety valve is activated. This issue is rated as a low priority item (3c) and appears to be acceptable to the agency.
- **Orleans Avenue Canal Pump Station Sump Design:** No physical model study was conducted of the Orleans Avenue Canal's pump station sump. ERDC's opinion was that the modifications developed at London Avenue would be equally effective at Orleans Avenue. The modifications developed at London Avenue were installed at Orleans Avenue. Although the station should have been modeled to confirm the design that was developed at London Avenue, the potential abnormalities that can occur are likely to be a maintenance issue. However, since the station was not modeled to confirm the design, the vulnerability for this station is 2C.
- **17th Street Canal Pump Station Sump Design:** Due to the accepted performance standards (see ANSI/HI standards criteria for "infrequent pump operating conditions" as stated in the ERDC January 2008 Report) for the model sump test of the approach flow to the pump station, there is the potential for accelerated wear on the pump impeller and bearings. However, at this station the modifications recommended by ERDC were not implemented. Not constructing and installing the recommended modifications might result in performance issues, such as cavitation damage, vibration, and bearing wear. These abnormalities will likely develop over time. Since the pumps have been operated during the last two hurricanes, it is recommended that a pump from each side of the canal be checked and assessed for damage to the impeller and bearings operations and maintenance as part of an ongoing maintenance plan. If abnormalities arise, the design modifications to the sump should be implemented to improve flow to the pumps. The vulnerability for this station is 2B.

3.6 Maintenance Vulnerabilities

3.6.1 Findings

This section identifies maintenance components and processes of the temporary pump stations and their support systems that will enhance successful performance of the stations.

Table 3-5—Maintenance Vulnerabilities

Source or Cause of Potential Vulnerability	Affected Pump Stations			Assessed Categories	
	17th Street	Orleans	London	Criticality	Vulnerability
Viscosity change and contamination of hydraulic oil	x	x	x	3	c
Corrosion of hydraulic pipe fittings and structure that are sumerged	x	x	x	3	c
Degradation of impeller due to vortices		x	x	2	c
Degradation of impeller due to vortices	x			2	b
Erosion of canal bottom & wall due to high water velocities at pump intake & discharge	x	x	x	3	c
Criticality: 1 – High; 2 – Medium; and 3 – Low Vulnerability: a – Extreme; b – Moderate; and c – Slight Note: Refer to Tables 3-1 and 3-2 for more information.					

- **Viscosity change and contamination of hydraulic oil:** Over time the viscosity of the hydraulic oil will change due to pump running and age of the oil. This is rated a low priority; however, there should be a maintenance routine included in the maintenance program.

- **Corrosion of hydraulic pipe fittings and parts of the structure that are submerged**: Since the pipe fittings and the structure that support the pumps are of different materials, bi-metallic corrosion is inevitable. The corrosion of these components will cause failures over time and routine subaqueous checks should be included in the maintenance program.

- **Degradation of impeller due to vortices:** Vortices can cause premature wear of the impeller and bearings due to cavitation. Minimizing pumping operations at levels where vortices will occur is recommended. Consideration should be given to the cost versus benefit of conducting a subsurface monitoring program to ensure that excessive wear of the impellers has not occurred. Additionally, close monitoring of the pumps during operation to determine if vibrations, not previously observed, begin to occur. Should unusual vibrations occur, the removal of pumps for inspection and bearing evaluation may be necessary.

- **Erosion of canal structure due to high velocities:** Erosion of canal structure may occur during actual high discharge events. A periodic subsurface monitoring system will mitigate this risk. These subsurface monitoring activities should be conducted in such a way as to allow for restorative activities before the wet season.

3.7 Pump Capacity Analysis

The design rainfall event serves as the basis of this analysis to determine the required and calculated pumping capacity for the 17th Street, London Avenue, and Orleans Avenue temporary pump stations. For the purpose of this report, this event is noted as the design rainfall event. These temporary pump stations have each been constructed relatively near the outlet of each canal into Lake Pontchartrain, and upstream of a new temporary gate structure. Existing SWB pump stations pump stormwater from urban drainage areas into the respective canal that serves the area. During Hurricane Katrina, the water level in Lake Pontchartrain rose due to storm surge and the effective pumping capacity of the SWB pump stations is decreased. The floodgates near the end of each of the canals are intended to protect the canals from excessive water stage levels while the temporary pumping stations are intended to pump the water from the drainage canals to Lake Pontchartrain. This arrangement maintains safe canal water levels and avoids failure of the protective levees on either side of the canals. These safe water levels were established by the USACE geotechnical engineers and are unique to each canal. This analysis is based on the maintenance of these safe water levels during the design rainfall event.

Simulated hydrographs were developed by USACE for each pump station indicating that the peak flow rates for the design rain event do not exceed 6 hours. Table 3-6 shows the required pumping capacities for each temporary pump station were extrapolated using the provided hydrographs for each canal.

Table 3-6—10-Year Peak Discharges Extrapolated from Hydrographs

Canal Pump Station	10-Year Peak Discharge (cfs)	10-Year Peak Discharge (cfs rounded)
17th Street	7,673	7,700
London Avenue	4,961	5,000
Orleans Avenue	1,883	1,900

Pumping capacities at each temporary canal pump station were determined using the following assumptions:

- Performance is based on the prototype water pump curve corrected to 288 rpm at the Rineer water pump.
- Field operating friction losses in the pump discharge and manifold piping using the Hazen-Williams friction factor C equals140 and varying K factors to establish losses due to elbow friction, entrance losses, and manifold friction losses.
- The approximate maximum flow anticipated from the hydraulic drive pumps at each location is based on operation at the canal safe water level that provides the lowest static head.

Installed pumping capacities of the hydraulic pumps at each temporary canal pump stations and their respective installed conditions are shown below in Table 3-7.

Table 3-7—Installed Hydraulic Drive Pumping Capacities

Location	Orleans Avenue	London Avenue	17th Street
Safe Water Level Elevation (ft)	8	5	6
Top of Discharge Pipe Elevation	11	11	12
Static Head	3	6	6
Total Number of Hydraulic Pumps	10	12	18
Calculated Discharge per Pump (cfs)	220	216	215
Total Calculated Capacity (cfs)	2,201	2,594	3,864

Although analysis of the direct drive pumping units at both the 17th Street Canal and London Avenue Canal and the portable pumping units at the 17th Street Canal are outside the scope of this report, the stated capacity of these additional pumps is as shown in Table 3-8.

Table 3-8—Total Stated Capacity of Additional Pumps

Pumps	17th Street (cfs)	London Avenue (cfs)
Direct	4,000	2500
Portable	1400	
Total	5400	2500

Therefore, based on the above listed and calculated capacity of the hydraulic pumps and the provided capacity of the direct drive and portable pumps, the capacity of the pumping stations has been determined to meet or exceed the required pumping capacity as indicated during the design rainfall event and is summarized in Table 3-9.

Table 3-9—Total Calculated Pump Station Capacity vs. Total Required

Items	17th Street (cfs)	London Avenue (cfs)	Orleans Avenue (cfs)
Hydraulic Pumps	3,864	2,594	2,201
Direct Drive Pumps	4,000	2,500	0
Portable Pumps	1,400	0	0
Total Capacity	9,264	5,094	2,201
Total Required	7,673	4,961	1,883

3.8.1 Mechanical

The hydraulic pump system consists of the diesel engine drive unit, the Denison hydraulic pump, the hydraulic pipe system, and the Rineer hydraulic water pump. The following is a discussion regarding each of these principle elements:

Diesel Engines: The diesel engines powering the hydraulic drive pumps, as manufactured by Caterpillar, are adequate for the specified operating conditions. It is the judgment of the Parsons team that these engines and identical models have been adequately tested to perform reliably in the service intended. The operating speed of these engines at 1800 rpm is consistent with current industry standards for diesel engines serving the water resource industry; therefore, it is a system with a high precedent.

Denison Hydraulic Pump: In general, pump hydraulic drive systems (including the hydraulic motors mounted on the pumps and the hydraulic pumps mounted on the diesel engines) have been sized to operate at or near the limits of their capabilities to produce torque and horsepower for pump operation under specified conditions. Field test results indicate that horsepower and torque capacity are slightly less than specified and than indicated in factory tests. However, those results are within tolerances allowed for field testing by the ANSI/HI. To avoid excessive maintenance and premature failure of the hydraulic drive systems, the hydraulic motor manufacturer has recommended a normal operating pressure of 3,200 pounds per square inch gauge (psig) during normal and continuous operation. To date, the hydraulic drive systems have performed as required and without abnormal maintenance or failures during Hurricane Gustav and other storm events.

During the site visit and through interviews with the USACE maintenance organization, it was discovered that the Aeroquip fitting on the Denison pump is experiencing intermittent leakage, in the form of a fine mist. It is our understanding that this leakage is due to a flange interface detail that is currently being addressed between USACE and the manufacturer. Resolution to this issue is encouraged.

Hydraulic Pipe System: The existing piping system that was used to deliver pressurized hydraulic oil to the Rineer hydraulic water pump was reviewed for adequacy. This analysis resulted in a confirmation that the pipe wall thickness meets or exceeds the requirements as stated in the ASME, B31, 31.3 as applicable for 3,200 psi hydraulic oil. The piping system as witnessed during the site investigations was unprotected from corrosion. It is our understanding that an effort is currently in place to coat the piping in order to avoid excessive corrosion.

Rineer Hydraulic Motor: This unit is used to drive the pump and receives its thrust via the hydraulic oil delivered from the Denison hydraulic pump. As discussed in Section 2, Testing Adequacy Analysis, the Rineer motor experienced a pulsing effect during the acceptance testing period. The replacement of the springs appears to have corrected this anomaly and the system has performed satisfactorily since.

3.8.2 Electrical

The electrical distribution (for all three pump stations, the standby generators, and the associated switches that control the distribution for the hydraulic pumps) were checked for reliability and compliance. The pump stations are powered from the local utility (Entergy) distribution 100 kVA transformers, with a secondary voltage of 240 volts, single phase, 60 Hertz (Hz) on the east bank and west bank of the canals. The electrical construction drawings were reviewed and electrical load calculations performed indicated the following: the electrical load for the 17th Street Canal temporary pump station was 88 kVA; the Orleans Avenue Canal temporary pump station was 73 kVA; and the London Avenue Canal temporary pump station was 71 kVA, on each side of the canal as shown in electrical service calculations.

Switches, panels, and generator sizes for all the stations were verified and found that the fused main disconnects, panels, automatic transfer switches, and service and branch cables were correctly sized for the full load of the pump stations. Calculations showed that the backup generator was correctly sized at 100 kVA for loads of 88 kVA, 73 kVA, and 71 kVA per side of the pump stations. In each station, there were additional 100 kVA generators configured to take over the backup generators in event of a backup generator failure.

The electrical lighting was examined, and it was noted that the lighting fixtures over the engine platforms were of the vapor proof fluorescent type fixtures. These fixtures are for wet areas, but they are not designed for hurricane force conditions. Therefore, they could potentially fall and destroy critical components of the pump.

The pole mounted light fixtures along the bridges and walkways designated Type F6 in the construction drawings are not designed for hurricane force conditions. Therefore, they could become flying debris.

The instrumentation and control systems were checked. The system uses a local area network architecture linking all the local control panels to a supervisory control and data acquisition (SCADA) system with multimode fiber optic cables. This architecture allows communication between control panels and the SCADA system using the Modbus messaging protocol. The network is a ring network topology allowing for media redundancy. All hydraulic pumping systems are equipped with local controls that are autonomous and do not entirely rely on the SCADA system for control. Therefore, they provide redundancy to the entire control system.

The USACE temporary pump stations are connected to the SWB pump stations upstream of the canals via fiber optic cables. This allows bidirectional control of the USACE temporary pump stations from either the SWB pump stations or the USACE temporary pump stations. The communication system is further supported with redundancy using a microwave radio communication local area network transmitting at 11 gigahertz (GHz). This wireless medium provides transmission of SCADA functions over Ethernet, voice over Internet Protocol (IP), and video surveillance to observe functionality of pumps and gates. This arrangement provides an effective multipoint to point transmission system to communicate between the temporary outflow pump stations and SWB stations using Ethernet over the wireless system. For further redundancy in voice communications, the temporary pump stations operational staff is equipped with satellite phones and police band radio sets as well, totaling to 4 different methods of voice communications.

3.8.3 Structural

A limited evaluation of the existing structural systems was performed at 17th Street, London Avenue, and Orleans Avenue Canal outfalls. The evaluation is based on onsite observation for condition assessment and cursory analysis of the primary landside support systems. The systems observed and their associated evaluations are as follows:

Landside Support Structure and Building: The supporting structures for the pumping systems consist of steel pipe piles at 17th Street and H-piles at both Orleans Avenue and London Avenue. Visual observation of these structures indicates that their condition is satisfactory although no protective coatings were used. A cursory analysis indicates that the gravitational capacity of the floor system meets or exceeds the requirements of the ASCE 7-02 recommendations. ASCE 7-02 is the applicable standard for this installation which provides minimum design loads for buildings and other structures. The wind loads used for the pre-engineered building were also evaluated. Again, the loads used met or exceeded ASCE 7-02 recommendations.

Control Room: During emergency response events, the operators occupy the control room at each of the subject canal pumping stations. The room is constructed of thick concrete walls, heavy steel doors, and the air conditioning unit that is hardened with steel framing providing protection from wind pressures and flying debris. These evidential observations indicate that the control room meets or exceeds the minimum requirements for wind protection.

Erosion Protection: A cursory review of the general configuration and activities conducted relating to the erosion protection before and after the flood wall was included in this review. The erosion protection consists of rip-rap protection ranging from 2 to 4 feet in thickness over a soil cement substrate. It is the Parsons team’s opinion that due diligence was exercised in this effort.

Windborne Debris: The landside station hydraulic drive systems are somewhat protected by a chain link fence that surrounds the platform. The waterside hydraulic drive systems at the 17th Street Station are unprotected. Given the excess capacity at the 17th Street station this exposure risk is mitigated. The chain link protection is unsupported between the column supports. Additional support for the chain link fence would improve its flying debris protective benefit.

3.8.4 Operational

The operational procedures for the temporary pump systems were reviewed with the HPO. The operational procedures include continuous communication with the New Orleans SWB representative at the upstream pump station. Communications, as described in the Electrical Section of this report, includes redundant systems including fiber-optic line connections, radio, microwave and out-of-state cell phones.

A review of the Operations Instruction Manual (OIM) indicates that the procedures in place meet expectations for pre-storm, storm and post-storm activities. Substantially, the OIM provides detailed descriptions for the following:

- Safe canal levels
- Gate closure
- Pumping activities
- Organizational and chain of command structure
- Fuel supply
- Electrical power
- Water level controls
- Equipment failure and diagnostic procedures
- Reporting and logging protocol

It is the Parsons team's opinion that the collaboration between the HPO and the SWB is essential to successful operations of the flood control system. Substantially, the cooperative operation of the two pumping systems tends to create a condition whereby the rise in canal levels between the stations reduces overall pumping capacity of the SWB due to the increased tailwater while increasing the capacity of the Temporary Pump Stations due to the reduction in total dynamic head. Historical data regarding the Gustav and Ike events indicates that the operational plan was successful.

3.8.5 Maintenance

The maintenance plan was reviewed using the check list provided by the HPO to the Parsons team. The plan indicates elements of the system that are checked and the frequency of those verifications. The plan includes checks of the following elements of the system:

- Engine before start
- Hydraulic system
- Engine pre-start
- Hydraulic system after start before engaging
- Hydraulic system after start and after engaging
- SCADA system

This review indicates that the primary pump system components are subject to verification and a log of the operating record is maintained to document performance. The performance logs for all hydraulic pumping systems including their support systems were provided by HPO. This performance log indicates that only minor corrections have been required since the completion of the installation acceptance testing.

The maintenance program is sufficient for its intended purpose with regard to the machinery elements. In order to maintain, reliability of diesel drives and hydraulic pumping units, periodic operation of the system is recommended by the manufacturer. The Parsons team understands that the systems are started every 2 weeks during the hurricane season and once per month during the off season. This is considered satisfactory for maintaining the reliability of the system.

There is no indication that a subsurface monitoring program is currently in place. Pumping systems, especially those in salt water or brackish water conditions, should be checked periodically to verify that excessive corrosion has not occurred. Additionally, the erosion protection system (rip-rap upstream and downstream) cannot be verified without the benefit of subsurface monitoring. Finally, as indicated in the Section 2, Testing Adequacy Analysis of this report, periodic visual inspection of the pump impellers to verify that excessive wear has not occurred as a function of the potential vortices is not included in the maintenance program. The Parsons team suggests that subsurface monitoring could be useful to the maintenance program. Typically, this could be conducted before each hurricane season and in time to enact mitigation actions, if necessary.

The current logging effort is conducted using a local data base and the forms as prepared by HPO. We understand that the HPO is currently preparing to participate in a computer based maintenance management system called the USACE Facilities & Equipment Maintenance System (FEM) that will allow for tracking trends associated with the reporting of maintenance and operational activities. It is the Parsons team's opinion that the use of this program, properly applied, will increase the reliability and predictability of the system.

No significant vulnerabilities were identified with regard to the existing maintenance program.

3.9 Conclusions

3.9.1 Mechanical

The Parsons team conclusions for mechanical systems vulnerability are as follows:

- The design rainfall event used to size the temporary canal pump stations has peak flow duration on the order of 4 to 6 hours and this criterion limits substantially the duration needed for the peak pumping rate.
- Installed pumping capacity at the 17th Street, the Orleans Avenue, and London Avenue pumping station meets or exceeds the service intended.
- The diesel engines are appropriately sized and are suitable for their intended use.
- The Denison hydraulic pump and motor, despite earlier issues with the cam wear and selection, are sized correctly and are demonstrating a high level of reliability evidenced by the recent performance during the Gustav and Ike storm events.
- The applicable standard for the power transmission piping (hydraulic oil) is the ASME B31, 31.3. Pipe thickness calculations were completed based on the guidance within B31, 31.3 as was appropriate and sufficient.
- The Rineer motor driving the water pump experienced the pulsing conditions during the acceptance testing period. The replacement of the spring system appears to have

rectified that issue and their performance appears to be suitable for their intended purpose.

3.9.2 Electrical

Parsons team's conclusions for electrical systems vulnerability are as follows:

- It is the Parsons team's opinion the electrical distribution and double backup systems are capable of full power and standby power distribution for the hydraulic pumps, which fully complies with the National Fire Protection Association (NFPA) Code 70 for all three stations.
- The vulnerability of the light fixtures is not detrimental to the operation of the temporary pump station. The asset risk level, for both the fluorescent fixtures and the pole mounted fixtures are determined at Level 3c.
- It is the Parsons team's opinion that there is enough redundancy in the communications system for effective, reliable communication, and control of the interim pump stations during an emergency response.

3.9.3 Structural

Parsons team's conclusions for structure and building vulnerability are as follows:

- The landside support structure and building were reviewed for capacity and compared to the requirements of ASCE 7. This evaluation indicates that the structures meet or exceed the minimum requirements for design loads as prescribed by ASCE 7.
- The Control Room was observed during a site visit and the construction is consistent with the requirements for wind load resistance as required by ASCE 7.
- The erosion protection system for the flood gates is consistent with industry standards for structures of this type.
- There are no apparent vulnerabilities associated with the structural system as designed and constructed.

3.9.4 Operational

Parsons team's conclusions for operational vulnerability are as follows:

- The operations requirements are outlined in the OIM. This manual indicates due diligence was exercised in its creation.
- The operations protocol includes close coordination between USACE and the SWB during storm events.
- This, coupled with redundant communications systems indicates that no apparent vulnerabilities are associated with the operational plan and implementation program.

3.9.5 Maintenance

Parsons team's conclusions for maintenance vulnerability are as follows:

- The maintenance program is outlined in the form of a checklist for the mechanics to follow during routine maintenance of the pumping systems. This outline appears to satisfactorily meet the objective of proper mechanical maintenance and is considered satisfactory for maintaining the reliability of the system.

- The plan does not indicate a subsurface monitoring system that is considered beneficial to verifying that the structures below the water surface are not exhibiting excessive corrosion, excessive degradation of pump components and is also considered beneficial to verifying that the erosion protection system has not degraded.

3.10 2008 Performance during Hurricanes Gustav and Ike

The Parsons team reviewed the Temporary Outflow Canal Pumps performance reports for the two hurricanes Gustav and Ike and gathered the following information:

3.10.1 Hurricane Gustav

On August 31, 2008, Hurricane Gustav made landfall, but New Orleans escaped the full force of the hurricane as the storm entered near the town of Cocodrie, Louisiana. The hurricane was a Category 2 storm, but the Louisiana coast experienced torrential rain and high winds of approximately 100 mph, which generated a storm surge in Lake Pontchartrain.

The USACE team received orders the next day to close the canal gates at the temporary outflow canal pump stations, cutting off the canals outflow to Lake Pontchartrain in anticipation of the storm surge associated with the high winds.

The records from USACE show that at the London Avenue Canal's temporary pump station all of the hydraulic and direct drive pumps were put into service. The total flow from the SWB pumps was 5,050 cfs on that day. With both, the hydraulic pumps and the direct drive pumps running at the London Avenue Canal pump station, the total flow pumped into Lake Pontchartrain was 5200 cfs, reducing the level of the canal down to a safe level. The London Avenue Canal temporary pump station ran for 27 minutes, matching the discharge from the SWB and maintained a safe water level in the London Avenue Canal. After the first 27 minutes, 4 hydraulic pumps were shut down as the canal level got too low for the pumps to function efficiently. The 4 hydraulic pumps were started again after 48 minutes and all pumps ran for another 55 minutes before the 4 hydraulic pumps were shut down again due to low levels in the canal. The hydraulic pumps ran for 3 days intermittently with various numbers of pumps taken in and out of service to control the canal level with the gates shut for 36 hours. Out of the 12 hydraulic pumps in service, 2 pumps were taken out of service due to minor malfunctions. The fault on one was a disconnected control wire, and the second was a loose flange bolt. There were no pump mechanical malfunctions. These pumping activities are summarized in Table 3-10.

The records show that at the 17th Street Canal temporary pump station and all of the hydraulic and direct drive pumps, except the portable pumps, were put into service. The total flow from the SWB pumps was approximately 5,050 cfs. With all available pumps running at the 17th Street Canal's temporary pump station (the portable pumps were not included), the total flow pumped into Lake Pontchartrain was approximately 7,240 cfs. The 17th Street Canal temporary pump station ran for 52 minutes, matching the discharge from the SWB and kept the level of the 17th Street Canal at a safe level. After the 52 minutes, all direct drive pumps, with the exception of 2 pumps, were taken out of service, leaving all hydraulic pumps running for 1 hour. As the canal water level dropped, the 2 direct drive pumps were taken out of service leaving all hydraulic pumps running. The hydraulic pumps ran for 2 days intermittently with various numbers of pumps taken in and out of service to control the canal level with the flood gates shut for a total of 18 hours. Out of the 18 hydraulic pumps in service, 1 hydraulic pump was taken out of service due to a hydraulic leak on a drive unit. There were no other pump mechanical malfunctions. These pumping activities are summarized in Table 3-11.

3.10.2 Hurricane Ike

On the morning of September 12, 2008, Hurricane Ike approached landfall as a Category 3 wind force generating a storm surge in Lake Pontchartrain of approximately 5.2 feet.

The records show that the USACE team experienced rain and winds of around 25 mph at the temporary pump stations, when they received orders to close the canal gates cutting off the canal's outflow to Lake Pontchartrain.

Records show that the west bank direct drive pumps were put into service at the London Avenue Canal temporary pump station. The total flow from the SWB pumps was approximately 1,000 cfs, with the pumps running at the London Avenue Canal temporary pump station; the total flow pumped into Lake Pontchartrain was approximately 1,200 cfs. The London Avenue Canal temporary pump station ran for 58 minutes, matching the discharge from the SWB and kept the level of the London Avenue Canal at a safe level. After the first 58 minutes, 2 direct drive pumps were shut down as the canal water level dropped too low for the pumps to function efficiently. An hour and 10 minutes later, 6 hydraulic pumps were started again and ran for another 35 minutes before the hydraulic pumps were shutdown again as the canal level got low. The hydraulic pumps ran for 4 days intermittently with various numbers of pumps taken in and out of service to control the canal level with the gates shut for 60 hours. There were no pump malfunctions during this hurricane event, as can be seen in Table 3-12.

Records show that at the 17th Street Canal temporary pump station, 10 direct drive pumps, and 6 hydraulic pumps were put in service. The total flow from the SWB pumps was 4,500 cfs, with 10 direct drive pumps and 6 hydraulic pumps running at the 17th Street Canal temporary pump station, the total flow pumped into Lake Pontchartrain was 5,200 cfs. The hydraulic pumps ran for 2 days intermittently with various numbers of pumps taken in and out of service to control the canal level with the gates shut for 36 hours. Out of the 18 hydraulic pumps in service, 1 hydraulic pump was taken out of service due to a hydraulic hose leak on a drive unit. There were no other pump mechanical malfunctions, as can be seen in Table 3-13.

Records show that while the storm surge was not enough to close the gates at the Orleans Avenue Canal, the USACE canal team decided to take advantage of the water levels to exercise the pumps and 10 hydraulic pumps were put in service at the Orleans Avenue Canal pump station. The 5 east bank pumps were put in service first and ran for 3 hours, the total flow pumped into Lake Pontchartrain was 1,044 cfs. After 3 hours, the pumps were taken out of service and the west bank pumps were put in service and ran for 3 hours at 1,054 cfs. The hydraulic pumps ran for two periods of 3 hours each. Total amount of water pumped at this facility was over 22 million gallons in this period without any pump major malfunctions with the 10 pumps. One HPU experienced a high temperature oil indication that turned out to be an electrical short circuit. This was repaired and the HPU was put back in service. These pumping activities are recorded in Table 3-14.

3.10.3 Conclusions

Parsons team's conclusions area as follows:

1. During Hurricane Gustav the following occurred:
   - Two pumps at the London Avenue Canal temporary pump station had minor malfunctions, one a loose bolt and the second, a loose control wire.
   - A direct drive pump and a hydraulic pump at the 17th Street Canal temporary pump station had minor malfunctions; the direct drive experienced a loose control wire, and the hydraulic pump experienced a leak in the hydraulic drive unit hose.
2. During Hurricane Ike the following occurred:
   - There were no pump malfunctions at the London Avenue Canal temporary pump station during the hurricane.
   - One hydraulic pump experienced a failure in the hydraulic hose at the 17th Street Canal temporary pump station.
3. Pump Activities during Hurricane Gustav:

   The pump activities during Hurricane Gustav are summarized in Tables 3-10, and 3-11. As shown in Tables 3-10 and 3-11, the total number of hydraulic pump hours for London Avenue was 105.3 pump hours and for the 17th Avenue was 224.5 pump hours. The total number of direct drive pump hours for London Avenue was 75.2 pump hours and for the 17th Avenue was 28 pump hours. As shown in both pump stations values, the hydraulic pumps were mainly used to bring the canal levels down. It took 3 hours to bring the canal down by 2 feet.
4. Pump Activities during Hurricane Ike:

   The pump activities during Hurricane Ike are summarized in Tables 3-12 and 3-13. As shown in Tables 3-12 and 3-13, the total number of hydraulic pump hours for London Avenue was 15.93 pump hours and for the 17th Avenue was 28.6 pump hours. The total number of direct drive pump hours for London Avenue was 60 pump hours and for the 17th Avenue was 76.4 pump hours. As shown in both pump station tables, the direct drives were used more than the hydraulic pumps to bring the canal levels down.

In Hurricane Gustav, two stations pumped a total of more than 1.7 billion gallons of water (pump rates were quoted by the USACE) into Lake Pontchartrain with two hydraulic pumps experiencing minor malfunctions. In Hurricane Ike, the two stations pumped a total of approximately half a billion gallons of water (pump rates were quoted by the USACE) into Lake Pontchartrain with one hydraulic pump experiencing a malfunction.

During Hurricane Ike the hydraulic pumps at the Orleans Avenue Canal Pump Station were tested for performance. The gates were not shut as the canal was at a safe level of 5.2 feet. The pumps were tested successfully with pumps running at near maximum output with one minor malfunction.

Minor pump malfunctions are expected for a large group of pumps such as this installation. The industry MTBF (mean time between failures) ANSI standard for a single axial pump continually running is 2.5 years between failures in the U.S. This means it is expected that a single axial pump continuously running will breakdown within a 2.5-year period. With hydraulic pumps, one can expect a much lower MTBF value as additional drive components (besides the engine prime mover) such as the hydraulic drive unit adds to the probability of failure. It can be expected that a hydraulic-driven pump will have a lower MTBF, and it will be more prone to failures than a single prime mover pump. However, these pumps will be used infrequently versus one that will run continuously for 2.5 years. This will, therefore, inevitably prolong the life of the pump to a much greater extent than a standard continuously running pump.

HPO Interim Closure Structure (ICS) Records also show that randomly selected pumps ran at near the recommended 3,200 psi hydraulic pressure, proving that these pumps are capable of the recommended pressures. Most of the pumps ran at an average of 80 to 95% of the recommended pressure. While these pumps are capable of the recommended extents, it is not normal practice in all industries to run machinery at maximum performance. This is inefficient and causes undue mechanical stress to any mechanical system, which will result in premature failure of components.

The Parsons team is satisfied that the pumps have functioned to industry standards, and the team is confident that the pumps will perform as designed and constructed to cope with the design rainfall event.

Table 3-10—London Avenue ICS – Hurricane Gustav Outfall Canal Closure Activities

LONDON AVENUE ICS - HURRICANE GUSTAV OUTFALL CANAL CLOSURE ACTIVITIES

Time		Run Time mins	Hydraulic Pumps												DD Drv Pumps								Total Hydraulic Pump Flow CFS	Volume Pumped Gallons by Hydraulic pumps	Total Direct Drive Flow CFS	Volume Pumped Gallons by Direct Drive pumps	Canal Level in Ft.	Comments
			E1	E2	E3	E4	E5	E6	W 1	W 2	W 3	W 4	W 5	W 6	E7	E8	E9	E1 0	W 7	W 8	W 9	W 10						
September 1, 2008																												
19:16	19:25	9													●	●	●	●	●	●	●	●		0	2,400	9,694,080	4.2	
19:25	19:52	27	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	2,800	33,929,280	2,400	29,082,240	4.2	
19:52	20:40	48													●	●	●	●	●	●	●	●		0	2,400	51,701,760	4.2	
20:40	21:35	55	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	2,800	69,115,200	2,400	59,241,600	4.2	
21:35	22:05	30	●	●	●	●	●	●	●	●	●	●	●	●					●	●	●	●	480	6,462,720	1,200	16,156,800	4.2	Reduced Speed of Hydraulic Pumps
22:05	0:00	115	●	●	●	●	●	●	●	●	●	●	●	●									1,800	92,901,600		0	2.5	
September 2, 2008																												
00:00	01:40	100				●	●				●		●	●									750	33,660,000	750	33,660,000	2.5	
01:40	04:20	160							●	●	●		●	●									500	35,904,000		0	2.5	
07:10	07:56	46	●	●	●	●	●	●	●	●	●	●	●	●									1,200	24,773,760		0	2.5	
07:56	08:40	44							●	●	●	●	●	●									600	11,848,320		0	2.5	
08:40	10:10	90							●	●	●												300	12,117,600		0	2.5	1cf = 7.48 us gal
13:58	15:15	77													●	●	●	●	●	●	●	●		0	2,400	82,938,240	2.5	
16:15	17:30	75	●	●	●	●	●	●															600	20,196,000		0	2.5	
17:30	18:35	65							●	●	●	●	●	●									600	17,503,200		0	2.5	
18:35	19:30	55							●	●	●			●									1,200	29,620,800		0	2.5	2w-off line due to leaking hydraulic oil flange
19:30	20:20	50							●		●	●	●	●									800	17,952,000		0	2.5	4w-off line due to high gear oil temp.
22:50	23:50	60																			●	●		0	600	16,156,800	2.5	
September 3, 2008																												
05:15	16:10	655																	●	●	●	●		0	1,200	352,756,800		
06:10	06:20	10																	●	●				0	600	2,692,800		
06:20																								0		0		Gates Opened
	Total Hours	29.52	5.8	5.8	5.8	7.5	7.5	5.8	12.3	10.5	14.0	6.4	11.5	12.5	3.6	3.6	3.6	3.6	15.2	15.2	15.2	15.2	Total Gals.	405,984,480	Total Gals.	654,081,120		

Table 3-11—17th Street ICS – Hurricane Gustav Outfall Canal Closure Activities

17th STREET ICS - HURRICANE GUSTAV OUTFALL CANAL CLOSURE ACTIVITIES

Time		Run Time mins	Hydraulic Pumps																		DD Drv Pumps											Total Hydraulic Pump Flow CFS	Volume Pumped Gallons by Hydraulic pumps	Total Direct Drive Flow CFS	Volume Pumped Gallons by Direct Drive pumps	Comments
			E1	E2	E3	E4	E5	E6	E7	E8	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21					
September 1, 2008																																				
20:15	21:04	49																				●	●	●	●	●	●	●	●	●	●		0	3,600	79,168,320	
21:05	21:57	52	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	3,640	84,948,864	3,600	84,015,360	
21:58	22:59	61	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●										●	●	3,400	93,081,120	720	19,711,296	
23:00	0:00	60	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●												3,400	91,555,200	0	0	
September 2, 2008																																				
0:01	0:20	19	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●												3,400	28,992,480		0	
0:21	2:34	133	●	●	●	●	●	●																								1,200	71,628,480		0	
2:35	3:46	71																														0	0		0	
3:47	4:52	65	●	●	●	●	●	●																								1,200	35,006,400		0	
4:53	6:38	105																														0	0		0	
6:39	7:45	66	●	●	●	●	●	●																								1,200	35,544,960		0	
7:46	8:16	30																														0	0		0	
8:17	9:35	78	●	●	●	●	●	●																								1,200	42,007,680		0	
06:20																																			0	Gates open
	Total Hours	**13.15**	8.9	17.9	17.9	17.9	17.9	17.9	3.2	12.2	12.2	12.2	12.2	0.9	12.2	12.2	12.2	12.2	12.2	12.2		1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	2.7	11.7	**Total Gals.**	**482,765,184**	**Total Gals.**	**182,894,976**	No Breakdowns

Table 3-12—London Avenue ICS – Hurricane Ike Outfall Canal Closure Activities

LONDON AVENUE ICS - HURRICANE IKE OUTFALL CANAL CLOSURE ACTIVITIES

Time		Run Time mins	Hydraulic Pumps												DD Drv Pumps								Total Hydraulic Pump Flow CFS	Volume Pumped Gallons by Hydraulic pumps	Total Direct Drive Flow CFS	Volume Pumped Gallons by Direct Drive pumps	Canal Level in Ft.	Comments
			E1	E2	E3	E4	E5	E6	W1	W2	W3	W4	W5	W6	E7	E8	E9	E10	W7	W8	W9	W10						
September 11, 2008																												
23:57	0:55	58																	•	•	•	•		0	1,200	31,236,480		
September 12, 2008																												
0:55	13:00	715																			•	•		0	600	192,535,200		
4:10	4:21	11	•	•		•	•	•															700	3,455,760		0		
4:21	4:42	21	•	•	•	•	•	•															1,200	11,309,760		0		
4:42	4:45	3	•	•	•	•	•	•															420	565,488		0		
07:02	07:15	13																			•	•		0	600	3,500,640		
07:15	07:30	15																	•	•	•	•		0	1,200	8,078,400		
07:30	07:50	20													•	•	•	•	•	•	•	•		0	2,400	21,542,400		
07:50	07:58	8													•	•	•	•			•	•		0	1,800	6,462,720		
07:58	11:30	212																			•	•		0	600	57,087,360		
11:30	11:40	10																	•		•	•		0	900	4,039,200		
11:40	11:45	5							•	•	•	•	•	•					•		•	•	1,200	2,692,800	900	2,019,600		
11:45	12:20	35							•	•	•	•	•	•									1,200	18,849,600		0		
12:20	13:40	80							•	•	•												600	21,542,400		0		
13:40	14:30	50							•	•													400	8,976,000		0		
15:25	17:42	137																			•	•		0	600	36,891,360		
19:05	19:16	11																			•	•		0	600	2,962,080		
19:16	19:40	24																		•	•			0	600	6,462,720		
19:40	19:57	17																	•	•				0	600	4,577,760		
September 13, 2008																												
06:05	07:10	65																			•	•		0	600	17,503,200		
07:10	07:40	30															•	•			•	•		0	1,200	16,156,800		
07:40	08:08	28															•	•						0	600	7,539,840		
14:26	14:55	29													•	•								0	600	7,809,120		
14:55	15:15	20													•	•	•	•						0	1,200	10,771,200		
20:36	21:11	35							•	•	•	•	•	•									1,200	18,849,600		0		
21:11	21:39	28																			•	•		0	600	7,539,840		
21:39	22:03	24																	•	•	•	•		0	1,200	12,925,440		
September 14, 2008																												
08:10	09:00	50																	•	•	•	•		0	1,200	26,928,000		
09:00																												Gates Open
	Total Hours	**29.23**	0.58	0.58	0.40	0.40	0.40	0.40	3.42	3.42	2.58	1.25	1.25	1.25	1.28	1.28	1.77	1.77	3.32	3.47	23.75	23.35	Total Gals.	**86,241,408**	Total Gals.	**484,569,360**		

Table 3-13—17th Street ICS – Hurricane Ike Outfall Canal Closure Activities

17th STREET ICS - HURRICANE IKE OUTFALL CANAL CLOSURE ACTIVITIES

Time		Run Time mins	Hydraulic Pumps																		DD Drv Pumps											Total Hydraulic Pump Flow CFS	Volume Pumped Gallons by Hydraulic pumps	Total Direct Drive Flow CFS	Volume Pumped Gallons by Direct Drive pumps	Comments
			E1	E2	E3	E4	E5	E6	E7	E8	W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W 10	W 11	W 12	W 13	W 14	W 15	W 16	W 17	W 18	W 19	W 20	W 21					
September 12, 2008																																				
8:05	8:20	15																			●	●	●	●	●	●	●	●	●				0	3,240	21,811,680	
8:21	8:50	29																			●	●	●	●	●	●	●	●	●	●	●		0	4,000	52,060,800	
8:51	8:56	5	●	●	●	●	●	●													●	●	●	●	●	●	●	●	●	●	●	1,200	2,692,800	4,000	8,976,000	
8:57	9:05	8	●	●	●	●	●	●													●	●	●	●	●	●	●	●				1,170	4,200,768	2,910	10,448,064	
9:06	10:25	79	●	●	●	●	●	●	●	●																						1,600	56,728,320	0	0	
10:26	12:20	114	●	●	●	●	●	●																								1,200	61,395,840	0	0	
12:21	14:40	139																														0	0	0	0	
14:40	16:00	80															●	●	●	●												800	28,723,200	0	0	W-10 hose failure
16:01																																	0	0	0	
Total Hours		7.82	3.4	3.4	3.4	3.4	3.4	3.4	1.3	1.3							1.3	1.3	1.3	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.8	34.0	34.0	Total Gals.	153,740,928	Total Gals.	93,296,544	

Table 3-14—Orleans Avenue ICS – Hurricane Ike Outfall Canal Closure Activities

ORLEANS AVENUE ICS - HURRICANE IKE OUTFALL CANAL ACTIVITIES															
Time		Run Time mins	Hydraulic Pumps										Total Hydraulic Pump Flow CFS	Volume Pumped Gallons by Hydraulic pumps	Comments
			E1	E2	E3	E4	E5	W1	W2	W3	W4	W5			
September 12, 2008			CUBIC FEET PER SECOND												
14:30	14:45	15	208	208	208	210	210						1,044	7,028,208	
14:45	15:00	15	208	208	208	210	210						1,044	7,028,208	
15:00	15:15	15	208	208	208	210	210						1,044	7,028,208	
15:15	15:30	15	208	208	208	210	210						1,044	7,028,208	E5 - Oil Temp Sensor Failure
15:30	15:45	15	208	208	208	210							834	5,614,488	
15:45	16:00	15	208	208	208	210							834	5,614,488	
16:00	16:15	15	208	208	208	210							834	5,614,488	
16:15	16:30	15	208	208	208	210							834	5,614,488	
16:30	16:45	15	208	208	208	210							834	5,614,488	
16:45	17:00	15	208	208	208	210							834	5,614,488	
17:00	17:15	15	208	208	208	210							834	5,614,488	
17:15	17:30	15	208	208	208	210							834	5,614,488	
17:30	17:45	15	208	208	208	210							834	5,614,488	
18:00	18:15	15					210	208	208	208	220	210	1,264	8,509,248	E5 Restart test after repair
18:15	18:30	15					210	208	208	208	220	210	1,264	8,509,248	
18:30	18:45	15					210	208	208	208	220	210	1,264	8,509,248	
18:45	19:00	15					210	208	208	208	220	210	1,264	8,509,248	
19:00	19:15	15					210	208	208	208	220	210	1,264	8,509,248	
19:15	19:30	15					210	208	208	208	220	210	1,264	8,509,248	
19:30	19:45	15					210	208	208	208	220	210	1,264	8,509,248	
19:45	20:00	15					210	208	208	208	220	210	1,264	8,509,248	
20:00	20:15	15					210	208	208	208	220	210	1,264	8,509,248	
20:15	20:30	15					210	208	208	208	220	210	1,264	8,509,248	
20:30	20:45	15					210	208	208	208	220	210	1,264	8,509,248	
20:45	21:00	15						208	208	208	220	210	1,054	7,096,528	
21:00	21:15	15						208	208	208	220	210	1,054	7,096,528	
21:15	21:30	15						208	208	208	220	210	1,054	7,096,528	
21:30														0	
	Total Hours	3.50											Total Gals.	114,886,312	